Operation Heli-STAR - Aircraft Position Data

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Final Report

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16. Abstract

Operation Heli-STAR (Helicopter Short-Haul Transportation and Aviation Research) was established and operated in Atlanta, Georgia, during the period of the 1996 Centennial Olympic Games. Heli-STAR had three major thrusts: 1) the establishment and operation of a helicopter-based cargo transportation system, 2) the management of low-altitude air traffic in the airspace of an urban area, and 3) the collection and analysis of research and development data associated with items 1 and 2. Heli-STAR was a cooperative industry/government program that included parcel package shippers and couriers in the Atlanta area, the helicopter industry, aviation electronics manufacturers, the Federal Aviation Administration (FAA), the National Aeronautics and Space Administration (NASA), and support contractors.

Several detailed reports have been produced as a result of Operation Heli-STAR. These include 4 reports on acoustic measurements and associated analyses, and reports on the Heli-STAR tracking data including the data processing and retrieval system, the Heli-STAR cargo simulation, and the community response system. In addition, NASA's Advanced General Aviation Transport Experiments (AGATE) program has produced a report describing the Atlanta Communications Experiment (ACE) which produced the avionics and ground equipment using automatic dependent surveillance-broadcast (ADS-B) technology. This latter report is restricted to organizations belonging to NASA's AGATE industry consortium. A complete list of these reports is shown on the following page.

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Operation Heli-STAR Technical Reports

Volume 1 DOT/FAA/ND-97/9	Operation Heli-STAR - Summary and Major Findings; S. Fisher, FAA AND-710, Washington DC and E. McConkey, Science Applications International Corporation, Arlington, Virginia; Principal Editors; September 1997
Volume 2 DOT/FAA/ND-97/10	Operation Heli-STAR - Helicopter Noise Levels Near Dekalb Peachtree Airport; Krishan Ahuja, Robert Funk, Jeffrey Hsu, Marcie Benne, Mary L. Rivamonte, and Charles Stancil; Georgia Tech Research Institute, Atlanta, Georgia; September 1997
Volume 3 DOT/FAA/ND-97/11	Operation Heli-STAR - Helicopter Noise Annoyance Near Dekalb Peachtree Airport; Krishan Ahuja, Marcie Benne, Mary L. Rivamonte, Robert Funk, Jeffrey Hsu, and Charles Stancil; Georgia Tech Research Institute, Atlanta, Georgia; September 1997
Volume 4 DOT/FAA/ND-97/12	Operation Heli-STAR - Helicopter Noise at Heliports; Krishan Ahuja, Robert Funk, Jeffrey Hsu, and Charles Stancil; Georgia Tech Research Institute, Atlanta, Georgia; September 1997
Volume 5 DOT/FAA/ND-97/13	Operation Heli-STAR - Effects of Buildings on Helicopter Noise; Krishan Ahuja, Robert Funk, Jeffrey Hsu, Michael Heiges, and Charles Stancil; Georgia Tech Research Institute, Atlanta, Georgia; September 1997
Volume 6 DOT/FAA/ND-97/14	Operation Heli-STAR - Aircraft Position Data; Michael Heiges, Shabnam Khan; Georgia Tech Research Institute, Atlanta, Georgia, September 1997
Volume 7 DOT/FAA/ND-97/15	Operation Heli-STAR - Cargo Simulation System; Ellen Bass, and Chasles Stancil; Georgia Tech Research Institute, Atlanta, Georgia, September 1997
Volume 8 DOT/FAA/ND-97/16	Operation Heli-STAR - Community Involvement; Christine Eberhard and Bobbi Rupp; CommuniQuest, Inc., Manhattan Beach, California; September 1997
Volume 9 DOT/FAA/ND-97/17	Operation Heli-STAR - Atlanta Communication Experiment (ACE), AGATE Flight Systems Communication Work Package 1.4, (AGATE Restricted Information) (AGATE Flight Systems Communication Team), December 1996.

FOREWORD

This is Volume 6 of a 9-volume report documenting the activities and results of Operation Heli-STAR, the Atlanta Short-Haul Transportation System (ASTS). ASTS was a cooperative government/industry program that established a helicopter transportation system to support community of Atlanta during the 1996 Olympic games. Volumes 2 through 5 of this set of reports documents the noise studies that were performed during Operation Heli-STAR. The noise research was performed by Georgia Tech Research Institute (GTRI). GTRI also produced two additional reports documenting Operation Heli-STAR. Volume 6 describes the aircraft position data processing research, and Volume 7 documents a Cargo Simulation System that was used in support of Heli-STAR cargo operations. The research and development elements of Operation Heli-STAR were funded by the Federal Aviation Administration through Science Applications International Corporation (SAIC).

The GTRI manager of the overall ASTS program was Mr. C. Stancil. The Principal Investigator of the noise studies, reported in volumes 2 through 5, was Dr. K. K. Ahuja of GTRI. GTRI personnel responsible for making and analyzing day-to-day noise measurements were Dr. R. Funk and Mr. Jeff Hsu who were assisted by a team of 20 researchers. Ms. Marcie Benne, a graduate student from the School of Psychology lead the effort on the community survey reported in Volume 2. She was assisted by Ms. Mary Lynn Rivamonte, a student in the School of Aerospace Engineering. The authors are particularly grateful for Dr. Mike Heiges of GTRI for providing the helicopter altitudes and flight paths and to Mr. Stephen Williams, also of GTRI, for setting up the microphone locations for noise contour measurements.

The titles of the four volumes reporting noise research are:

Volume 2 - Helicopter Noise Levels Near Dekalb Peachtree Airport

Volume 3 - Helicopter Noise Annoyance Near Dekalb Peachtree Airport

Volume 4 - Helicopter Noise at Heliports

Volume 5 - Effects of Buildings on Helicopter Noise

The titles of the other two volumes authored by GTRI are:

Volume 6 - Aircraft Position Data

Volume 7 - Cargo Simulation System

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1.0 INTRODUCTION

The 1996 Centennial Summer Olympic Games in Atlanta, GA were seen by several industry, government, and academic research groups as an excellent opportunity to demonstrate the capabilities of vertical flight. Before the arrival of the games, a number of priority package shippers were concerned that restricted ground traffic during the games would require them to move cargo by helicopter. In an effort to promote this type of aviation activity and assess its impact, the Federal Aviation Administration (FAA) General Aviation and Vertical Flight Program Office (AND-710) sponsored the Atlanta Short-Haul Transportation System (Heli-STAR) program under the direction of the Georgia Tech Research Institute (GTRI), Aerospace and Transportation Lab. This report describes the Heli-STAR program with an analysis of flight trajectory data from pre-Olympic preparatory flights through the actual cargo hauling missions.

1.1 HELICOPTER SHORT-HAUL TRANSPORTATION AND AVIATION RESEARCH (Heli-STAR) PROGRAM

A number of priority package shippers including Federal Express, United Parcel Service, and DHL along with several banks joined together to form the Atlanta Vertical Flight Association (AVFA). The AVFA represented a united user group with the Helicopter Association International (HAI) as its spokesman. The AVFA's goal was to urge the FAA to establish the infrastructure necessary for increased, efficient vertical flight activity by the time of the Olympic Games. The Headquarters FAA General Aviation and Vertical Flight office (AND-710) sponsored a research and development project to develop a low level route structure with numerous landing sites. AND-710 also sponsored a demonstration (which it called HELI-STAR) of helicopter short-haul activity using communication, navigation, and surveillance (CNS) technologies for flight following and asset management. Key to managing the helicopter cargo operations was the ability to track the aircraft along the low level route system with new technologies such as GPS and datalink.

1.2 PURPOSE OF TRACKING AIRCRAFT

The Heli-STAR aircraft were tracked for the purposes of conducting several studies. First is an assessment of the economic viability of using helicopters to ship time critical cargo short distances in an urban environment. Another study seeks to determine the impact of increased helicopter activity on environmental noise and community acceptance. The aircraft tracking system itself is evaluated on its suitability for flight following and asset management, and on its potential for air traffic control.

1.2.1 Economic Analysis

Aircraft track histories were processed to generate data for a number of studies including an economic analysis of the short-haul demonstration. The information obtained from the track data includes aircraft tail number, takeoff and landing sites, departure, arrival, and flight times, and average cruise speed. The processed data is stored in a database for use in an assessment of helicopter transport economic viability. This economic study is contained in a companion volume to this report.

1.2.2 Acoustic Tests

A series of approaches, departures, and fly-overs were conducted in an attempt to map out the acoustic footprint of a conventional helicopter. Various speeds and approach angles were flown to determine their effects on the aircraft's acoustic footprint. The flights were made over a microphone array located around a dedicated landing site. The recorded sound pressure data is being processed to represent the footprint as a set of noise level contours. The aircraft's position is correlated to the microphone readings through GPS time and coordinates. This effort is the first major helicopter acoustics test to be conducted in an urban environment where the effects of buildings and terrain on noise propagation will be examined. This acoustics study, contained in a companion volume, represents a significant first step in developing methodologies for predicting the impact of heliport operations in an urban setting. The data gathered in the Heli-STAR project is pertinent to pure helicopter operations as well as combined fixed-wing and helicopter operations at a general aviation (GA) airport.

1.2.3 Air Traffic Control Interests

The expanded use of rotorcraft on an extensive low level route structure presents a challenge in terms of air traffic control (ATC). New technologies were demonstrated during Heli-STAR that allowed flight following and digital communications between the aircraft and a ground monitoring station using a single piece of navigation equipment. The FAA and other law enforcement agencies, such as U.S. Customs, were interested in this technology because it allowed them to identify, track, and advise suitably equipped aircraft. Another issue of interest is aircraft separation; using non-precision GPS, how tightly do aircraft fly the route particularly in areas where there are few route markers? The study of these issues is a first step to developing a low level air traffic control system that relies on GPS for navigation and guidance and would ultimately permit IFR operations. Eventually, many of the low altitude air traffic control functions could be automated leading to an increased use of the airspace without overburdening the ATC system.

1.3 ENABLING TECHNOLOGIES - GPS AND DATALINK

Major challenges to conducting extensive helicopter operations on a low level route structure include giving ATC controllers the ability to track aircraft and to communicate with them and giving pilots the ability to "see" other aircraft and to navigate safely around a metropolitan area (obstacle rich environment). Under the current paradigm, the air traffic controller relies on a radar based surveillance system to track aircraft. The pilot uses a separate radio based system for navigation and depends upon the controller to advise him of traffic beyond his visual range. A radar based surveillance system can be costly if it requires a large number of radar and sophisticated methods for detecting aircraft in a cluttered urban environment. Furthermore, this type of system does not provide the aircraft pilot an ability to "see" other aircraft. Communications can become impaired if too many transmissions saturate the frequencies used for advisories and control. The inability to transmit instructions to individual aircraft only further aggravates the saturation problem.

Two technologies, GPS and datalink, have been combined to solve these problems in a single low cost system. During the Heli-STAR demonstration the aircraft were tracked with a datalink system that transmitted aircraft GPS receiver data to a ground monitoring station. The datalink also provided the capability for discreet communications between the ground station and the aircraft. Aircraft equipped with MFD's could use the system to navigate and "see" other aircraft using the same system.

1.3.1 Global Positioning System (GPS)

The NAVSTAR Global Positioning System (GPS) is a space-based radio positioning network providing highly accurate position, velocity, and time information to properly equipped users (Ref. 1-3). It was developed by the U.S. Department of Defense as a satellite-based radio navigation system to meet the navigation needs of a broad spectrum of users, both military and civilian.

The system consists of three segments: space, control, and user (see figure 1.1). The *space segment* comprises 24 satellites which continuously transmit ranging signals and system status messages. The satellites orbit at an altitude of 10,898 nautical miles in six 55 degree orbital planes, with 4 satellites in each plane (see figure 1.2). The orbital period of each satellite is approximately 12 hours. The *control segment* consists of ground-based monitoring stations which track each satellite and periodically upload to the satellite predictions of future satellite positions and satellite clock time corrections (see figure 1.3). Receivers in the *user segment* track the ranging signals of selected satellites and calculate three-dimensional position and local time.

GPS positioning is based on time of arrival (TOA) ranging. In simplistic terms, range to a satellite can be determined from a radio signal given the precise time of transmission, the time of arrival, and the speed of the signal. Knowing the position of each satellite (the ephemeris) which is transmitted in the satellite signal and the distance of the receiver to the satellites, the receiver's processor can determine the three dimensional position of the user.

GPS Satelite

User

GPS Monitoring Station
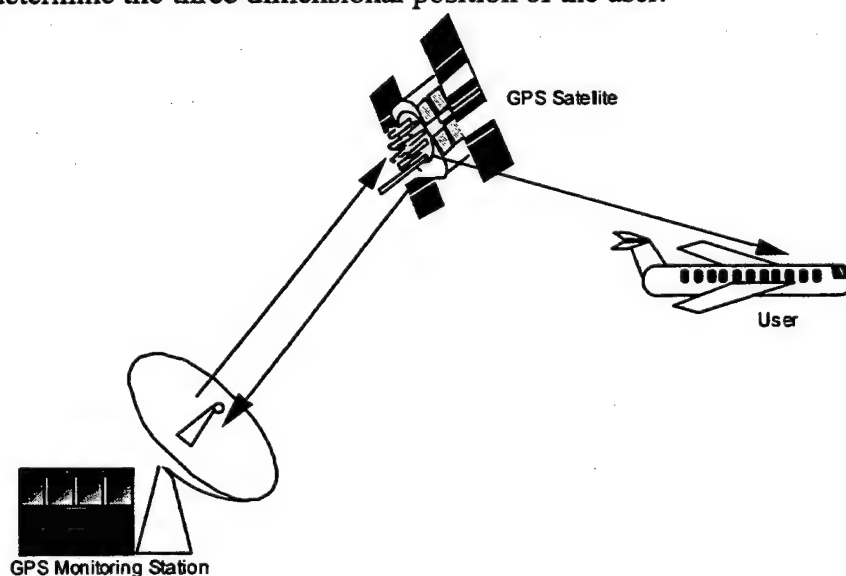
Figure 1.1 The NAVSTAR Global Positioning System

1 - 3
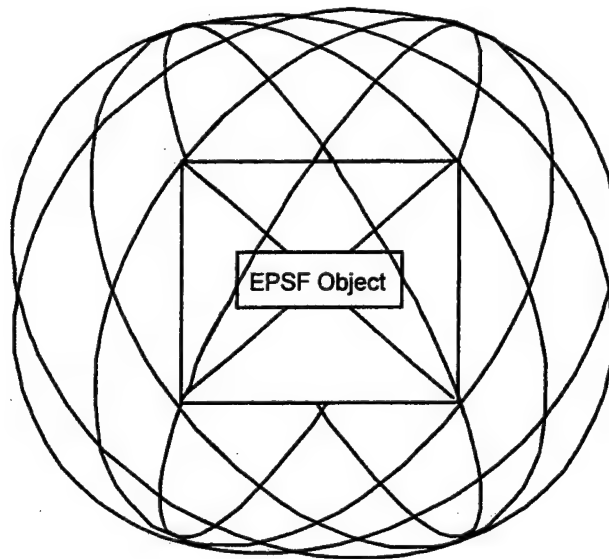
Figure 1.2 GPS Satellite Constellation

Figure 1.3 Control Segment of GPS

Because of the radio signal's speed (the speed of light), extremely accurate timing is required to establish distance. This is accomplished by determining a correction to the receiver clock time based on the signal from the GPS satellites which have very accurate clocks. Solving for the four unknown quantities, three dimensional position coordinates plus the clock correction, requires signals from four satellites. If more than four satellites are in view, the receiver selects the four that will provide the most accurate position solution. Military users can expect three dimensional position accuracy of 10 m rms or better and velocity accuracy less than 0.1 m/sec. Accuracy for civilian users is about 100 m or better in all three dimensions. Positioning accuracy is a function

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of both ranging accuracy (distance to the satellites) and the satellite geometry relative to the receiver.

The major cause of ranging errors for civilian users is known as *Selective Availability*. For reasons of security, military operators of the system have the capability to degrade the accuracy of the civilian ranging signal intentionally by desynchronizing the satellite clock, or by incorporating small errors in the broadcast ephemeris. This degradation is termed Selective Availability (SA). SA typically causes about a 20 m rms ranging error resulting in position errors of 41 m horizontal and 51 m vertical. The Department of Defense has guaranteed that SA errors will be limited so that the positioning error will be kept to less than 100 m horizontal and 156 m vertical.

The second major source of ranging errors is the ionosphere layer of the earth's atmosphere. The free electrons in the ionosphere create a delay in the GPS ranging signal proportional to the integrated number of free electrons along the transmission path and inversely proportional to the square of the transmission frequency. Ionospheric electron density can be highly variable. Military GPS users have access to ranging signals at two frequencies (L_1, L_2) which can be used to correct for ionospheric effects. This technique can reduce the ranging error due to the ionosphere down to 1-2 m. Civilian users do not have access to the L_2 frequency and corrections must be estimated based on an ionosphere model. Mismodeling of the ionosphere results in ranging errors of about 2-5 m. Compared to the effects of SA, ionosphere mismodeling errors are rather small. Without SA civilian receivers could achieve a horizontal positioning accuracy of about 10 m, comparable to military accuracy.

In addition to ranging errors, positioning accuracy is affected by the relative geometry of the satellites being tracked by the GPS receiver. This effect, termed *Dilution of Precision (DOP)*, consists of Position Dilution of Precision (PDOP) and Time Dilution of Precision (TDOP), collectively called geometric Dilution of Precision (GDOP). PDOP is made up of horizontal (HDOP) and vertical (VDOP) components. PDOP represents a multiplier that is applied to the total ranging error to determine the position error. Since PDOP is a multiplier, the smaller it is, the better the positioning accuracy is. Currently, the worldwide median PDOP value is approximately 2.5 with typical values of 2.0 for HDOP and 2.5 for VDOP. Generally, if the PDOP value rises above six, the satellite geometry is not very good. Low PDOP values occur when the satellites are widely spaced in the sky above the GPS receiver. High values occur when the satellites are close together or form a row or a circle.

Much of the error in the civilian version of GPS can be overcome with a technique known as Differential GPS (DGPS). Differential corrections are made by placing a GPS receiving unit at a known, surveyed location to serve as a reference. This reference station compares the GPS signals that it observes against what it expects to see knowing its location. The differences between the observed and expected signals are broadcast by radio to other receivers as differential corrections. With DGPS, civilian units can be as accurate as military units using precision GPS. Corrections can be broadcast as either X-Y-Z position corrections or as pseudorange corrections for each satellite in view. The precision of the first method decreases rapidly as the distance between the reference station and the user's receiver grows. Also, this

method requires that the reference station and the user's receiver use the same set of satellites. The second method provides a correction for satellites in view and is thus the preferred method. GPS presents a powerful tool for positioning and navigation without requiring a significant equipment investment on the part of the user. By transmitting an aircraft's GPS position report to a ground station, a new method of aircraft tracking (called automatic dependent surveillance or ADS) becomes possible. The transmitting system, called a datalink, is described in the following section.

1.3.2 Datalink

Datalink refers to the digital communication system between aircraft and ground monitoring stations. VHF radio frequencies can be used to allow two-way communications consisting of position reports and traffic advisories. Typically the aircraft transmits its identification code, position, speed, heading, and altitude directly to a ground tracking station and to other aircraft. This allows the aircraft to be "seen" on a display screen without the use of secondary surveillance radar (SSR). A major advantage of this approach is the replacement of costly rotating SSR antennas with cheaper, non-rotating omnidirectional antennas. This could be a significant savings in the development of ATC infrastructure for low level routes which could require several antennas for adequate coverage.

Aircraft equipped with a suitable display unit can receive and respond to digitally coded advisory messages from the ground tracking station. The unit can also be used to display the location of other aircraft that are transmitting their positions. This provides an relatively inexpensive and accurate system for traffic alerts and collision avoidance.

2.0 TRACKING EQUIPMENT

The Heli-STAR economic, noise, and air traffic control studies required a time history of the aircraft's position during operations. Position data is necessary to establish time/distance factors, to correlate acoustic measurements and noise complaints, and to examine airspace usage. Tracking aircraft on a low level route structure in an urban area presented a challenge for the Heli-STAR demonstration. The use of surveillance radar would have been costly and would not have taken advantage of the advances that have been made with GPS and datalink technologies. Instead, an existing, low-cost commercial system supplied by ARNAV Systems, Inc. was chosen for tracking and navigation purposes.

2.1 ARNAV SYSTEM

The ARNAV Systems, Inc. GeoNet Adaptive Broadcast Datalink System (ABDS) is a network of fixed and mobile datalink hardware sites for vehicle tracking and wireless transfer of graphical weather maps, text messages, and sensor data. The network consists of individual GPS datalink transceivers (GeoLink) comprising a half-duplex VHF radio frequency modem, a GPS receiver, and an Input/Output microprocessor. The GeoLink may be pin configured as either a fixed or mobile unit. A mobile unit is usually installed in automobiles, aircraft, or other moving vehicles. The basic functions of a mobile unit are to: 1) provide a vehicle position, 2) broadcast the position to any other mobile or fixed units, 3) send messages to a host system, and 4) receive messages addressed to the mobile unit.

A fixed unit can be used as a base station, a repeater, or a ground based data router. Combining one of the fixed GeoLink units in the network with a PC workstation forms the GeoNet Control Station. The GeoNet Control Station is used to display a graphical map of the area with the position of all vehicles "layered" onto the map. Additional databases may also be layered on the graphical map. The GeoNet Control Station displays the network status and provides the permanent storage media for text messages and vehicle track data. It also formats text and graphics messages that are sent to the mobile nodes. A Monitor Station, having no control functions, can be connected to the Control Station as part of a local area network (LAN).

Figure 2.1 presents a schematic of a generic GeoNet system. Communications between the various GeoLink units is via radio frequency modems. The modems use a Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) scheme to manage the radio frequency (RF). Each GeoLink in the network monitors the RF saturation and makes decisions on interval reporting in order to minimize RF data collisions. With the CSMA/CA protocol 40 vehicles can update their position reporting within 5 seconds using one frequency. If more vehicles are in a given RF area, the GeoNet software allows for prioritization of user response. For example, aircraft on approach may use a 5 second reporting rate, while overflying aircraft may report every 30 seconds. By implementing prioritization based on flight mode, position, speed, or other user defined factors, many more vehicles can be tracked.
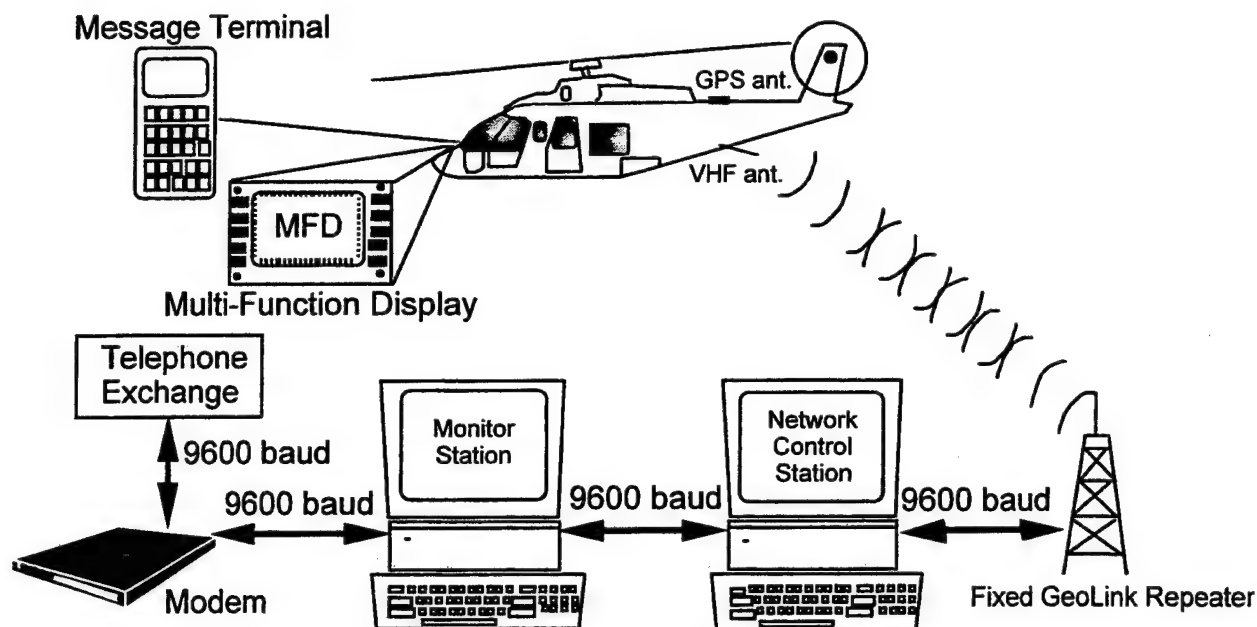
Figure 2.1 Generic GeoNet Configuration

2.1.1 Aircraft Installed Equipment

The Heli-STAR demonstration helicopters were each equipped with a mobile GeoLink unit. The basic functions of a mobile unit are to: 1) provide a vehicle position, 2) broadcast the position to any other mobile or fixed units, 3) send messages to a host system, and 4) receive messages addressed to the mobile unit.

There are two types of mobile units. Type one has a self contained GPS system to provide position information for datalink messages, and as an option, the GPS can be used as the source of navigation data to an ARNAV multi-function display (MFD). Type two has no internal GPS and needs to be connected to an ARNAV MFD or flight management system (FMS) for position data. All the Heli-STAR aircraft were equipped with type two systems connected to an ARNAV MFD 5200.

Specifications for the ABDS mobile transceiver are as follows:

Weight	3.1 lb
Size:	6.5 x 2.5 x 8.25 in
Input Voltage:	8-30 VDC
Input Power:	12 watts, maximum
Radio Modem	
Frequency:	149.895 MHz
Channels:	1
Data Rate:	9600 BPS GMSK
RF Power Out:	2 to 4 Watts
Antenna	
Manufacturer:	Commant

Model:	CI-177-1
Maximum Power In:	50 Watts
Gain:	Unity
Nominal Impedance:	50 Ohms
Element Length:	14.5 it
Radiation Pattern:	Omni-directional
Polarization:	Vertical

The ARNAV MFD 5200 is a graphics mapping system capable of interfacing with a variety of GPS receivers. It provides a graphical depiction of a number of navigation modes and information including a Jeppesen database card with over 40,000 waypoints. The system consists of a panel mounted Control Display Unit (CDU) and a remote mounted Line Replaceable Unit (LRU). The CDU contains the screen (a five-inch, color flat panel display) and 10 panel mounted menu option buttons. The LRU contains the Jeppesen datacard and communicates with the GPS receiver. The ARNAV 5200 MFD LRU connects to an RS232 port on the ABDS transceiver through an ARNAV Electronic Device Interface (EDI).

2.1.2 Ground Based Equipment

The ground based equipment used during the Heli-STAR demonstration included GeoLink units in fixed mode, antennas, several PC size computers, and a UNIX workstation hosting database software. The master control station was located at the Georgia Tech Research Institute facilities in Cobb Co. with repeater antennas located around the Atlanta metropolitan area. Heli-STAR operations were monitored from the master control station which was the source of aircraft track time history data for the project.

2.1.2.1 Master Control Station

GeoLink unit in fixed mode connected to an IBM compatible computer served as the master control station. The fixed mode GeoLink unit's functions are to: 1) pass all messages that come from an outbound path to the inbound path, and 2) repeat all inbound port messages to all outbound paths. The outbound paths are RF, and up to two RS232c ports and the inbound path is RF. Specifications for a fixed site transceiver are the same as for the mobile configuration; the main difference is in the antenna specifications which are as follows:

Antenna

Manufacturer:	Cellwave
Model:	BA1012 W/n275f
Maximum Power In:	150 Watts
Gain:	3 dB
Nominal Impedance:	50 Ohms
Element Length:	9.2 ft
Radiation Pattern:	Omni-directional
Polarization:	Vertical

The master control station computer requires a minimum of 640k of memory, VGA video adapter and monitor (17 in or larger is recommended), bus mouse, two RS232 serial ports, and a hard drive with at least 500 MBytes of storage. This storage is used to automatically record all communications, position reports, and airborne weather phenomena. GeoNet Network Control software is hosted on the computer and monitors and records all network status parameters. This software was modified for the Heli-STAR demonstration to output daily a comma delimited, ASCII file containing such aircraft position data as: aircraft ID, report time, latitude, longitude, heading, altitude, and speed.

Communications Via Datalink. The GeoNet network uses a hierarchical routing scheme. Data traffic traveling towards the root of the network topology are considered inbound messages, while data traffic moving away from the root are considered outbound messages. The majority of message traffic in vehicle tracking applications are inbound position reports. The routing intelligence is distributed through all GeoLinks on the network. The primary purpose of each mobile node in the network is to periodically send position reports inbound. These messages are the mechanism by which vehicle tracking is achieved, but also serve the purpose of creating real time routing tables throughout the network. The routing tables provide a means of message routing and duplicate message detection.

Figure 2 shows an example of the network routing for two helicopters. Helicopter 1 sends a position report inbound to GeoLink #1 where it is sent through port C to the Network Control Terminal. Messages sent outbound to helicopter 1 through GeoLink #1 go out the RF port only. Helicopter 2 sends a position report inbound to GeoLink #2 where it is sent through port C to GeoLink #1 port D, then through GeoLink #1 port C to the Network Control Station. GeoLink #1 now knows that a message may be routed to helicopter 2 through GeoLink #1 outbound port D, thence to the GeoLink #2 RF port. Any messages sent from the Network Control Station to helicopter 2 will follow this routing until movement of the helicopter causes new routing tables to be created.
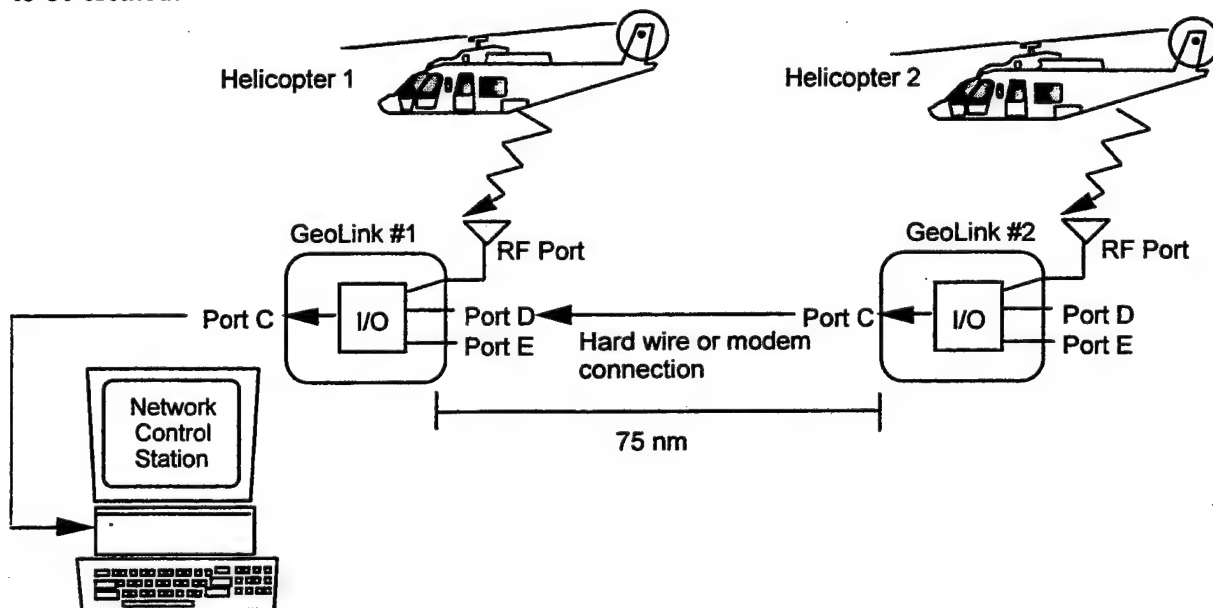
Figure 2.2 GeoLink Message Routing

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2.1.2.2 Repeater Antenna Sites

In order to obtain sufficient coverage, several GeoLink units were located around the Atlanta area to serve as repeaters. Figure 2.3 shows the location of the repeater antennas at the GTRI Cobb Co. facilities, DeKalb-Peachtree Airport (PDK), the Georgia Emergency Management Agency (GEMA), and Hartsfield International Airport (ATL). The extent of coverage was largely affected by the altitude at which the aircraft were flying. Aircraft cruising at 1000 ft above ground level could be tracked up to 148 km (80 nm) from a repeater. However, in some instances, aircraft operating near the ground could not be tracked at 10 km (5 nm) from a repeater.
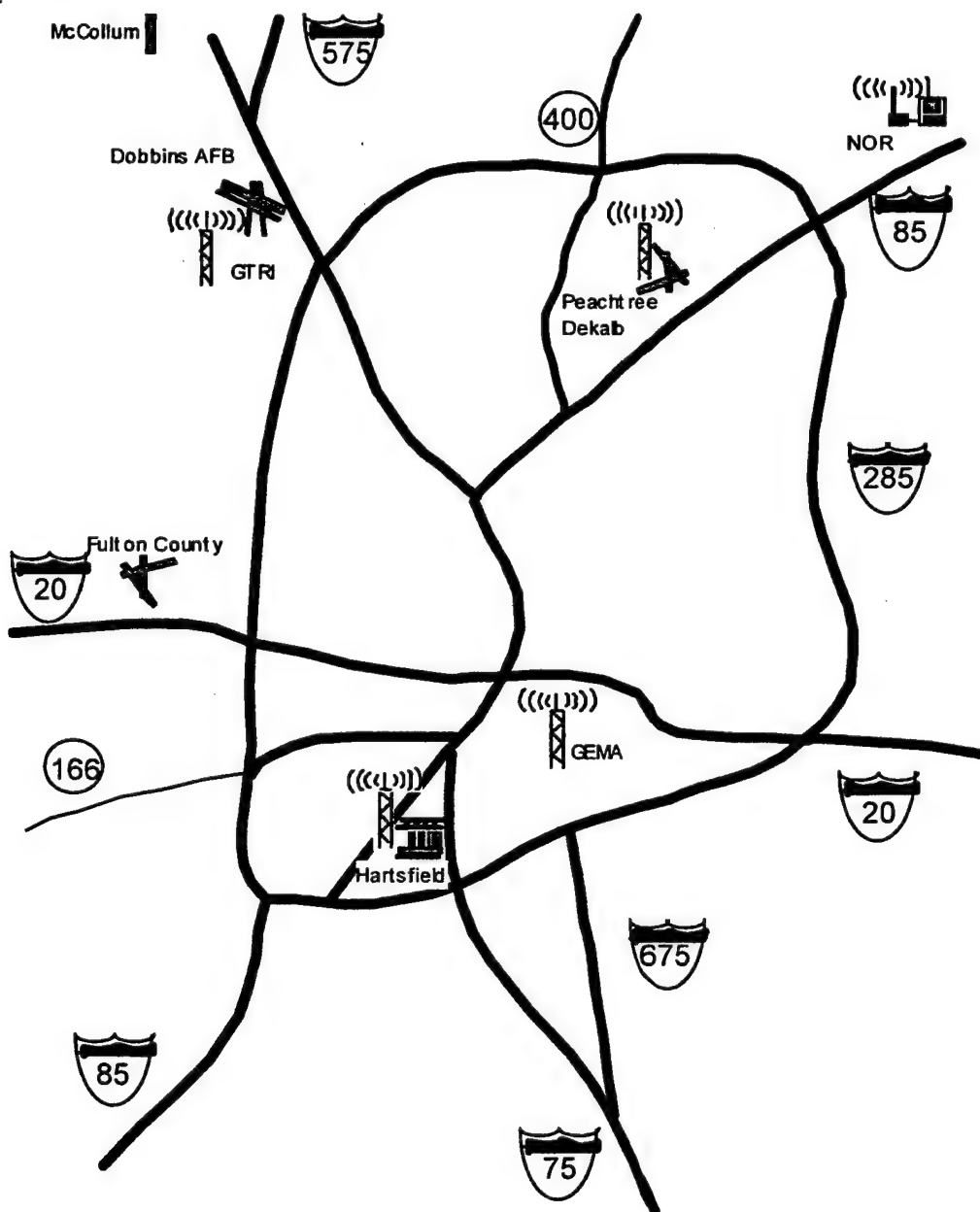
Figure 2.3 Location of GeoNet Repeater Units

2.1.2.3 Portable Ground Unit

A portable GeoLink unit connected to a laptop computer was used as an auxiliary ground station to record position data in areas not well covered by the main GeoNet system. This was required for tracking aircraft involved in acoustics studies at a site in northeast Atlanta (designated NOR on figure 2.3). The aircraft were operating near the ground during approach and landing and could not be tracked from the PDK repeater. The ground station was also connected to a GPS receiver which allowed the unit to be used as a reference point when it was stationary. This reference point was used to reduce the GPS position error of the tracked aircraft (details of this correction are described later in this report).

2.2 DATA PROCESSING/STORAGE EQUIPMENT

Aircraft track data was initially stored on the GeoNet Control Station in ARNAV proprietary formatted files. Each file contained the position data of all tracked aircraft for a 24 hour period. The files were then converted to comma delimited, ASCII files which were transferred to a MacIntosh Quadra 950 workstation for post-processing with GTRI proprietary software. Results of the post-processing were transferred to a HP9000 UNIX server hosting Oracle database software version 7.0.16.

3.0 TEST CONDITIONS

During the Heli-STAR demonstration a number of flight investigations were carried out. The two most significant investigations centered on flight operations and noise measurements. Data from these two areas were used to address issues of economic viability, community impact, and airspace utilization. Studies on the economic and acoustic aspects of the Heli-STAR demonstration are fully documented in companion reports. The intent of this section is to document the conditions under which aircraft track data was collected and processed for subsequent analyses.

3.1 Heli-STAR CARGO SHIPPING

Cargo shipping operations involved the use of six helicopters to transport time critical cargo around the Atlanta metropolitan area for a 13 day period during the 1996 Summer Olympic Games. The aircraft flew on low level routes that followed the interstate highway system for the most part. Landing zones were sited at several local airports and at selected shippers facilities. Flights were made on a regular, preplanned schedule.

3.1.1 Aircraft Types

Six helicopters were provided and operated by Petroleum Helicopters, Inc. (PHI) for the cargo operations. The fleet consisted of four Eurocopter BO105s (see figure 3.1) and two Bell Helicopter 412s (see figure 3.2). The BO105 specifications are as follows:

Main Rotor	
Diameter	9.84 m (32.3 ft)
Number of Blades	4
Tip Speed	218 m/sec (715 ft/sec)
Tail Rotor	
Diameter	1.9 m (6.2 ft)
Number of Blades	2
Tip Speed	221 m/sec (725 ft/sec)
Installed Power	1000 hp
Empty Weight	1,430 kg (3,153 lb)
Gross Weight	2,600 kg (5,732 lb)
Useful Load	1,170 kg (2,579 lb)
Max Cruise Speed	239 kmh (129 kts)
Max Rate of Climb	9.2 m/sec (1,810 ft/min)
Max Range Std Fuel (no reserve)	515 km (278 nm)

The Bell 412 specifications are as follows:

Main Rotor	
Diameter	14 m (46 ft)
Number of Blades	4
Tip Speed	238 m/s ec (780 ft/sec)
Tail Rotor	

Diameter	2.6 m (8.5 ft)
Number of Blades	2
Tip Speed	218 m/sec (716 ft/sec)
Installed Power	2,800 hp
Empty Weight	3,083 kg (6,798 lb)
Gross Weight	5,397 kg (11,900 lb)
Useful Load	2,314 kg (5,102 lb)
Max Cruise Speed	230 kmh (124 kts)
Max Rate of Climb	8.6 m/sec (1,690 ft/min)
Max Range Std Fuel (no reserve)	744 km (402 nm)
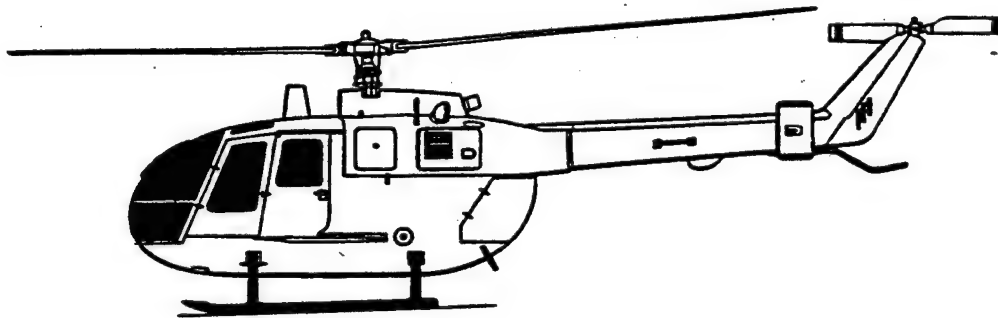
Figure 3.1 Eurocopter BO105
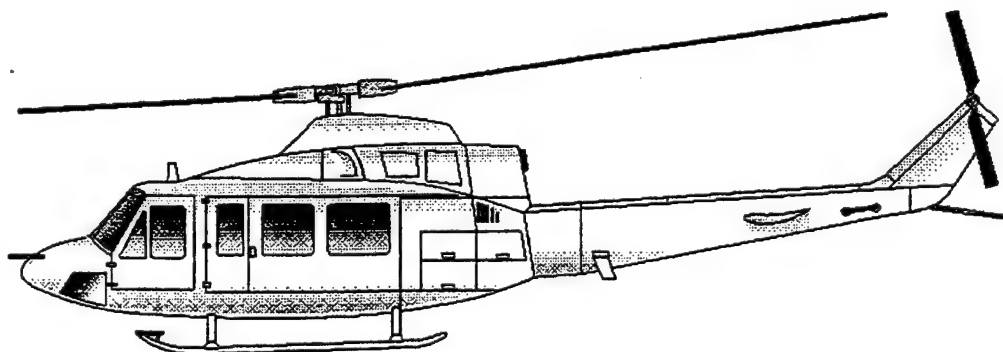
Figure 3.2 Bell Helicopter 412

3.1.2 Route Structure

A low level route structure was developed for use during the 1996 Summer Olympic Games. Also, approaches were designed for a number of landing sites in the metropolitan area.

3.1.2.1 Low Level Route Structure

Figure 3.3 shows the eight routes developed for use during the 1996 Olympic Games.
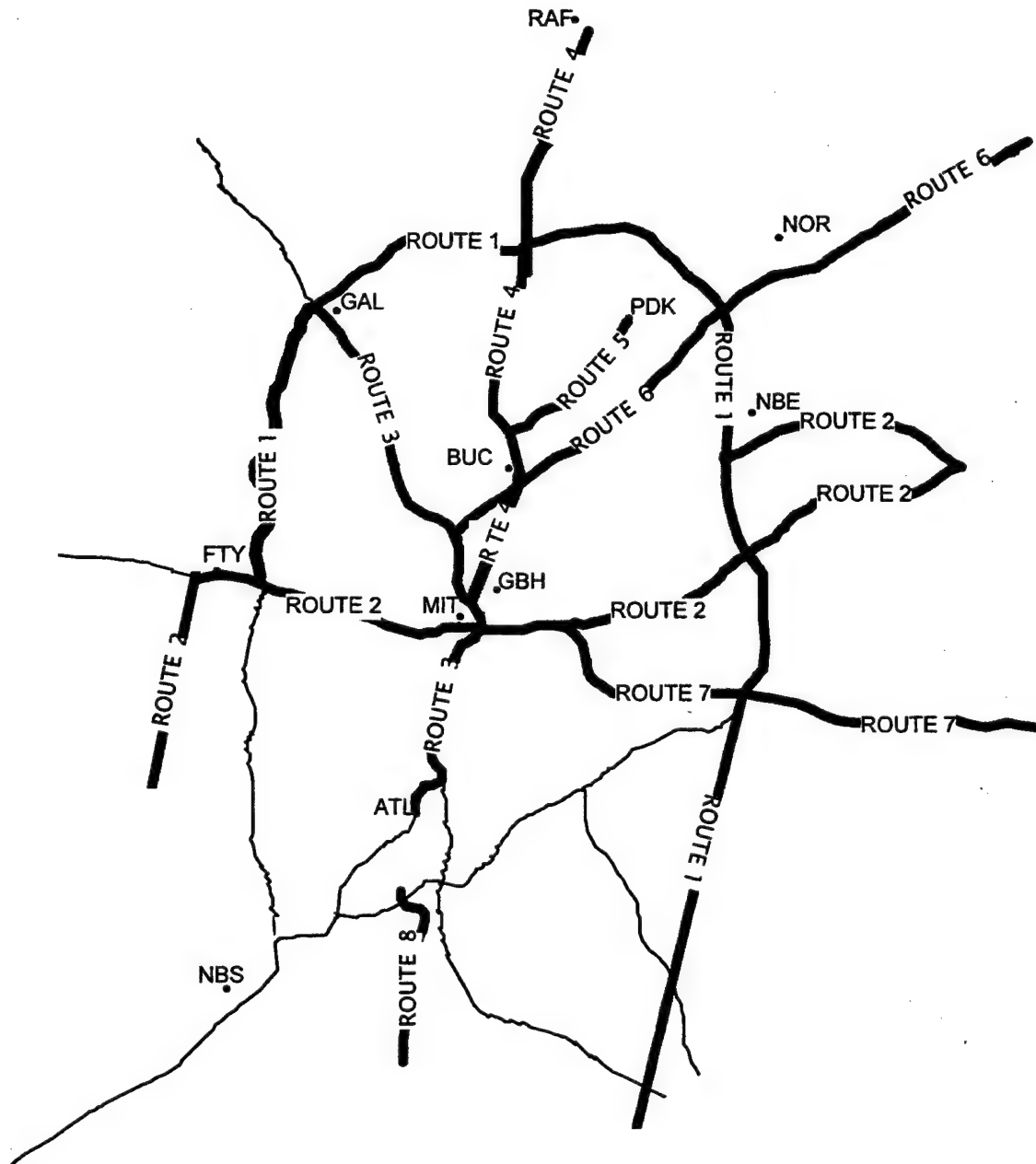
Figure 3.3 Low Level Route Structure

3.1.2.2 Landing Sites And Approach Waypoints

The cargo operations used 11 certified heliports located throughout the Atlanta metropolitan (see table 3.1 and figure 3.3). Each site was configured with perimeter lighting, lighted wind cone, beacon, and area lighting. In some cases, a VASI Approach lighting system was installed to assist pilots during their approach to the site (NOR). Three heliports were located at elevated sites (NBE, NBS, and GBH) and three were located at area airports (PDK, FTY, ATL). Other heliports were located at construction sites, parking lots, existing hospital helipads, and cleared areas. Appendix A contains the approach path waypoints for these sites.

Table 3.1 Landing Site Coordinates

Landing Site	Latitude (deg)	Longitude (deg)	Identifier
DeKalb-Peachtree Airport	33.884083	-84.306133	PDK
Atlanta Journal & Constitution, Norcross	33.919697	-84.227027	NOR
NationsBank Southside	33.589314	-84.515407	NBS
NationsBank Northside	33.842741	-84.241135	NBE
NationsBank Mitchell St.	33.751770	-84.395083	MIT
Georgia Baptist Hospital	33.762672	-84.373932	GBH
Fulton County Airport	33.772067	-84.520417	FTY
Hartsfield International Airport	33.665333	-84.420333	ATL
Wachovia Bank, Buckhead	33.817914	-84.368347	BUC
Galleria Mall	33.886550	-84.459133	GAL
N. Fulton County Hospital	34.059783	-84.324233	RAF

3.1.3 Scheduling

Flight operations were conducted on the basis of a regular, preplanned schedule. Typically, flights ran in a round-robin fashion from 7:00 am to 11:00 pm. Six helicopters flew routes consisting of 9-10 stops, averaging 1 hr and 10 min of flight time. Initially, these routes were repeated six times a day as shown in Appendix B. As the demonstration program progressed, the number of repetitions was reduced due to the lack of sufficient cargo.

3.1.4 Operating Regulations

Flights were conducted under Visual Flight Rules (VFR).

3.2 ACOUSTIC TESTS

An acoustics investigation was conducted as part of the overall the Heli-STAR demonstration program. One aspect of this study focused on mapping the contours of sound pressure beneath a helicopter for several flight regimes. The intent was to develop a model of aircraft noise "footprint" as a function of flight parameters such as speed, height above ground and descent angle. Another aspect of the acoustics study sought to determine the noise impact of increased helicopter activity around a general aviation airport. The results of the acoustics studies are fully

documented in companion reports. The scope of this report is to document the procedures used in acquiring aircraft track data for the acoustics studies.

3.2.1 Test Descriptions

The noise footprint investigation centered on making detailed measurements of noise contours beneath the helicopter in a setting with varying terrain features, including buildings. A helipad behind the Atlanta Journal-Constitution printing plant (NOR, see figure 3.?) was used as the test site. A microphone array recorded sound levels in landing operations for various approach angles and speeds. Noise levels were measured at a total of one hundred locations around the helipad. Only twenty-one noise measuring systems were available. The strategy of acquiring noise data at 100 locations, therefore, consisted of making measurements at 21 locations first for a given set of helicopter maneuvers. Twenty of the twenty-one microphones were then moved to another twenty locations. One microphone was kept at the same location to track variations in noise levels due to minor variations in ambient conditions. Repeating this procedure five times provided noise data at a total of 100 locations (and a reference location) at which detailed noise contours could be constructed.

The second acoustics study focused on the noise impact of increased helicopter activity at a GA airport. All noise monitoring for this study was done in the vicinity of the DeKalb-Peachtree Airport (PDK) northeast of Atlanta. This location was chosen because of mixed fixed-wing and rotary-wing operations and because of the greatly increased helicopter traffic expected during the Olympic period. Sound levels were measured at over fifty locations in the area around the helipad.

3.2.2 Aircraft Type

An FAA S-76A was dedicated to flying the test plan for the footprint mapping task (see figure 3.4). The specifications for the Sikorsky S-76 are as follows:

Main Rotor	
Diameter	13.4 m (44 ft)
Number of Blades	4
Tip Speed	205 m/s ec (675 ft/sec)
Tail Rotor	
Diameter	2.4 m (8. ft)
Number of Blades	4
Tip Speed	205 m/sec (674 ft/sec)
Installed Power	1,300 hp
Empty Weight	2,520 kg (5,546 lb)
Gross Weight	4,682 kg (10,300 lb)
Useful Load	2,161 kg (4,754 lb)
Max Cruise Speed	268 kmh (145 kts)
Max Rate of Climb	7.4 m/sec (1,460 ft/min)
Max Range Std Fuel (no reserve)	648 km (350 nm)

The aircraft was equipped with a GeoLink unit for position reporting. During the time that the aircraft was being tracked for position correlation with noise measurements, the report update rate was set to 1 sec through the master Control Station.
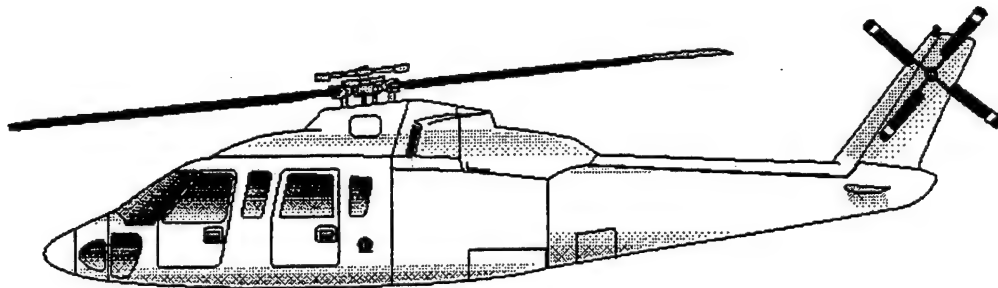
Figure 3.4 FAA S-76A

3.2.3 Acoustic Equipment

The microphone setups used in both acoustics investigations (at NOR and PDK) were the same. Each consisted of a sound level meter and a battery pack in a waterproof case and a tripod with a wind screen and rain protection for the microphone. A digital audio tape (DAT) recorder was used to record raw data. The meters were equipped with an internal clock to time stamp the acquired data and had a raw, line-level output from the microphone suitable for recording. The DAT recorder also contained an internal clock which time stamped the audio data recorded on the tape. Clock times for the recorders were synchronized with GPS clock time to allow temporal correlation of sound pressure recordings with aircraft position.

3.2.4 Test Procedures

For the footprint mapping task, a matrix of runs was designed to vary approach speed, approach angle, and aircraft weight. Three approach speeds, three approach angles and two weights were used. The weight parameter was varied due to fuel burn and presence of passengers. A set of approaches starting at high weight condition and a set starting at a lower weight condition were selected. Aircraft weight was recorded on board by the flight test engineer based on fuel weight passed from the pilots. Level fly-overs at various speeds were also done as fuel allowed. A table of the flights for each measurement configuration is shown in table 3.2. As was mentioned in the discussion about measurement locations, the test was done in five sets, denoted with flight cards A-E. The tests were scheduled based on the availability of the aircraft. Noise measurements corresponding to flight card A were carried out in the afternoon of 9 July 1996, flight cards B and C on 10 July 1996, and flight cards D and E on 17 July 1996.

For the second acoustics investigation, the impact of helicopter activity was measured in terms of changes to the day-night average sound level (DNL) contours around PDK. DNL levels were measured prior to the Olympics, during the Olympics, and after the Olympics. The pre-Olympic testing was done between 10 June 1996 and 27 June 1996. During the Olympics, measurements were made during the first week of the games, from 22 July 1996 to 26 July 1996. The final set of testing was done between 3 September 1996 and 12 September 1996 at a slightly reduced set of locations to determine if DNL values had returned to pre-Olympic levels. The total number of helicopter and fixed-wing operations were counted by the acoustic data acquisition operators who were monitoring the equipment. Ground tracks in the vicinity of the airport are readily available for aircraft equipped with ARNAV GeoLink units. Other aircraft ground tracks can be obtained from recorded PDK radar data; however, these data do not contain unique aircraft identifiers and have not been processed to the extent that the GPS data have.

Table 3.2 Flight Matrix For Each Noise Configuration

Run Number	Airspeed (knots)	Approach Angle (degrees)	
1	100	8.0	
2	80	8.0	
3	60	8.0	Higher
4	100	<8.0	Weight
5	80	<8.0	
6	60	<8.0	
7	100	>8.0	
8	80	>8.0	
9	60	>8.0	
10	100	8.0	
11	80	8.0	
12	60	8.0	Lower
13	100	<8.0	Weight
14	80	<8.0	
15	60	<8.0	
16	100	>8.0	
17	80	>8.0	
18	60	>8.0	

4. TEST RESULTS

Table 4.1 shows a sample print out from the GeoNet ABDS datafile in ASCII format. Each aircraft position report is tagged with the aircraft's identifier and the time at which the report was transmitted. The format for the position report is: aircraft tail number, GeoLink identifier, user code, latitude degrees, latitude minutes, longitude degrees, longitude minutes, ground speed (kts), track heading (deg), altitude (ft), time.

Table 4.1 Sample GeoNet ABDS Data File

```
GTRI ,202016,2a,33,54.608,84,31.584,0,79,1243.423,11:19:06
GTRI ,202016,2a,33,54.608,84,31.583,0,53,1269.67,11:19:17
N206E,202086,2a,33,43.141,84,21.453,35,170,1131.876,11:16:53
N38  ,201489,2a,34,2.112,84,18.782,144,31,1755.228,11:18:15
N38  ,201489,2a,34,2.695,84,18.355,144,31,1719.139,11:18:32
N38  ,201489,2a,34,2.965,84,18.164,137,30,1794.598,11:18:40
N38  ,201489,2a,34,3.542,84,18.003,114,329,1856.933,11:18:58
N3893,202021,2a,33,53.003,84,18.366,0,51,918.624,10:52:34
N3893,202021,2a,33,53.001,84,18.364,0,17,915.3432,10:52:46
N3893,202021,2a,33,53.001,84,18.364,0,51,918.624,10:52:58
N3893,202021,3a,33,53.002,84,18.364,0,27,918.624,10:53:02
N3A  ,202065,2a,33,45.383,84,22.123,9,192,2027.534,10:49:41
N3A  ,202065,2a,33,45.359,84,22.124,8,192,2011.13,10:49:54
N3A  ,202065,2a,33,45.293,84,22.135,6,190,1971.761,10:50:27
N3A  ,202065,2a,33,45.263,84,22.127,5,177,1968.48,10:50:45
N3A  ,202065,2a,33,45.244,84,22.122,7,191,1965.199,11:18:59
N610S,202022,2a,33,46.967,84,31.2,3,238,646.3176,02:03:04
N610S,202022,2a,33,46.96,84,31.208,4,226,646.3176,02:03:13
N610S,202022,2a,33,46.96,84,31.21,3,239,652.8792,02:03:17
N610S,202022,2a,33,46.964,84,31.22,3,271,662.7216,02:03:30
N724M,202018,2a,33,52.957,84,18.405,1,305,967.8361,11:07:55
N724M,202018,2a,33,52.956,84,18.405,1,307,961.2744,11:07:59
N724M,202018,2a,33,52.956,84,18.405,1,310,961.2744,11:08:03
N864C,201497,3a,33,46.734,84,31.03,3,251,856.2888,10:45:02
N911G,202007,2a,33,45.73,84,22.428,19,4,1295.916,05:43:27
N967M,202012,3a,33,39.229,84,25.573,37,186,859.5696,11:10:26
N967M,202012,2a,33,39.079,84,25.587,9,8,1122.034,11:18:56
NGUAR,201484,2a,33,55.077,84,30.229,0,76,767.7072,10:24:53
```

A sorting routine developed at GTRI was used to separate the data into individual aircraft track files. In addition, track data from the cargo operations and the acoustic test required a coordinate frame transformation. Position reports in degrees latitude and longitude were transformed to a local reference frame where distance to the landing site or to the microphones could be measured in lineal units (meters). Appendix C describes this transformation as presented in Ref. 4. The processed track file contains: the report time in hh:mm:ss format, the report time in terms of total seconds from midnight, relative position east of PDK (m), relative position north of PDK (m), local frame z coordinate (m), altitude (ft), track heading (deg), ground speed (kts), range to nearest landing site (m), bearing to nearest landing site (deg), and the identifier of the nearest landing site.

Table 4.2 Sample Processed Track Data

time	t(sec)	reast	rnorth	rz	alt	trk	speed	range	brng	site
10:54:52	39292	-76.3	-96.1	30.6	810.4	178.0	.0	122.7	38.4	PDK
10:54:59	39299	-79.1	-90.6	32.6	803.8	355.0	4.0	120.3	41.1	PDK
10:55:03	39303	-74.2	-75.8	33.6	800.5	14.0	9.0	106.1	44.4	PDK
10:55:07	39307	-66.4	-53.8	33.6	800.5	20.0	12.0	85.5	51.0	PDK
10:55:14	39314	-51.6	35.2	31.6	807.1	354.0	36.0	62.4	124.3	PDK
10:55:23	39323	-130.0	216.4	16.8	856.3	322.0	43.0	252.4	149.0	PDK
10:55:28	39328	-252.2	244.4	14.8	862.9	265.0	54.0	351.2	134.1	PDK
10:55:31	39331	-337.0	205.4	11.8	872.7	242.0	63.0	394.6	121.4	PDK
10:55:31	39331	-337.0	205.4	11.8	872.7	242.0	63.0	394.6	121.4	PDK
10:55:35	39335	-455.6	125.8	-.1	912.1	237.0	71.0	472.7	105.4	PDK
10:55:39	39339	-589.9	46.2	-11.1	948.2	240.0	78.0	591.7	94.5	PDK
10:55:43	39343	-739.6	-29.6	-23.0	987.5	244.0	83.0	740.2	87.7	PDK
10:55:52	39352	-1088.6	-235.0	-38.9	1040.0	234.0	91.0	1113.7	77.8	PDK
10:56:00	39360	-1392.4	-482.7	-58.8	1105.6	229.0	97.0	1473.7	70.9	PDK
10:56:04	39364	-1551.4	-613.9	-66.8	1131.9	231.0	100.0	1668.5	68.4	PDK
10:56:08	39368	-1718.1	-736.3	-75.7	1161.4	234.0	100.0	1869.3	66.8	PDK
10:56:12	39372	-1891.3	-852.7	-84.6	1190.9	236.0	102.0	2074.6	65.7	PDK
10:56:21	39381	-2265.8	-1165.2	-88.5	1204.1	224.0	109.0	2547.8	62.8	PDK
10:56:26	39386	-2446.7	-1390.9	-85.5	1194.2	216.0	113.0	2814.4	60.4	PDK
10:56:38	39398	-2798.7	-2009.1	-91.4	1213.9	206.0	115.0	3445.2	54.3	PDK
10:56:42	39402	-2900.5	-2227.2	-94.3	1223.7	204.0	115.0	3657.0	52.5	PDK
10:56:45	39405	-2973.4	-2390.2	-92.3	1217.2	203.0	116.0	3815.0	51.2	PDK
10:56:50	39410	-3098.5	-2660.4	-90.2	1210.6	205.0	116.0	4083.9	49.4	PDK
10:56:58	39418	-3358.0	-3050.3	-93.0	1220.5	219.0	113.0	4536.6	47.7	PDK
10:57:03	39423	-3572.9	-3244.6	-92.8	1220.5	230.0	113.0	4648.9	208.1	BUC
10:57:07	39427	-3754.6	-3389.0	-92.7	1220.5	231.0	113.0	4436.9	206.9	BUC
10:57:11	39431	-3927.8	-3546.0	-92.6	1220.5	226.0	114.0	4219.2	205.8	BUC
10:57:18	39438	-4202.8	-3855.1	-93.3	1223.7	221.0	115.0	3822.9	204.1	BUC
10:57:21	39441	-4323.0	-3986.3	-94.2	1227.0	222.0	115.0	3654.5	203.2	BUC
10:57:26	39446	-4531.6	-4195.4	-94.9	1230.3	226.0	114.0	3381.8	201.4	BUC
10:57:30	39450	-4706.2	-4350.7	-96.8	1236.9	228.0	114.0	3175.2	199.5	BUC
10:57:37	39457	-4968.6	-4670.8	-98.4	1243.4	210.0	116.0	2789.5	196.6	BUC
10:57:40	39460	-5023.1	-4844.4	-100.3	1250.0	194.0	118.0	2607.6	196.5	BUC
10:57:45	39465	-5026.1	-5149.7	-105.1	1266.4	177.0	118.0	2315.5	198.6	BUC
10:57:54	39474	-4953.6	-5686.4	-128.7	1345.1	168.0	115.0	1845.8	206.1	BUC
10:57:58	39478	-4893.6	-5918.1	-135.6	1368.1	164.0	116.0	1671.3	211.4	BUC
10:58:02	39482	-4818.1	-6143.8	-142.5	1391.1	161.0	116.0	1528.9	218.3	BUC
10:58:06	39486	-4734.8	-6365.8	-147.4	1407.5	159.0	116.0	1420.9	226.5	BUC
10:58:20	39500	-4550.0	-7183.7	-150.9	1420.6	177.0	117.0	1225.7	262.5	BUC
10:58:23	39503	-4557.9	-7363.2	-150.7	1420.6	183.0	118.0	1207.5	270.9	BUC

The data gathered during the Heli-STAR cargo operations was used to evaluate the system and address a number of issues. For instance, position report rates were determined as functions of aircraft location and installation to evaluate the system's coverage. A regime recognition algorithm was used to break track data down by flight by identifying take-off and landing times and locations. This data was stored in a database system for later economic and operational analyses. Track data from the acoustic footprint mapping task were used to determine the test aircraft's position relative to the recording microphones. This data was "cleaned up" on the basis of data from a local ground station and radar to reduce the position and altitude errors. The following subsections present the results from the Heli-STAR cargo operations and the acoustics tests.

4.1 Heli-STAR CARGO OPERATIONS

The Heli-STAR cargo operations provided an excellent opportunity to evaluate the effectiveness of the ARNAV datalink system in terms of update rates and coverage. The cargo aircraft flew on regular, pre-planned schedules with the pilots keeping an accurate log of the takeoff and landing times and locations. Comparing the logged information with datalink position reports made clear the effectiveness of the ARNAV system for monitoring aircraft movement. The pilot logs were also useful in verifying and correcting information stored in the database. Update rates/coverage and the database are discussed in the following subsections.

4.1.1 Update Rates And Coverage

Primary ATC radar typically take about 10 sec (en route) or 5 sec (terminal area) for a complete revolution. Thus, aircraft positions are updated once every 10 sec or 5 sec. This provides a standard for evaluating the suitability of using the GeoNet ABDS for aircraft surveillance. As stated earlier, with the CSMA/CA protocol 40 vehicles can update their position reporting within 5 seconds using one frequency. The update rates can be set from the Control Station and the update rates of the Heli-STAR aircraft were nominally set at 4 sec. Figure 4.1 presents an example of the update rate for aircraft N724MB on 22 June 1996. The figure shows that with the nominal update rate set to 4 sec, 33 percent of the position reports are 4 sec apart. The cumulative line indicates that 82 percent of the position reports are at an interval of 10 sec or less.
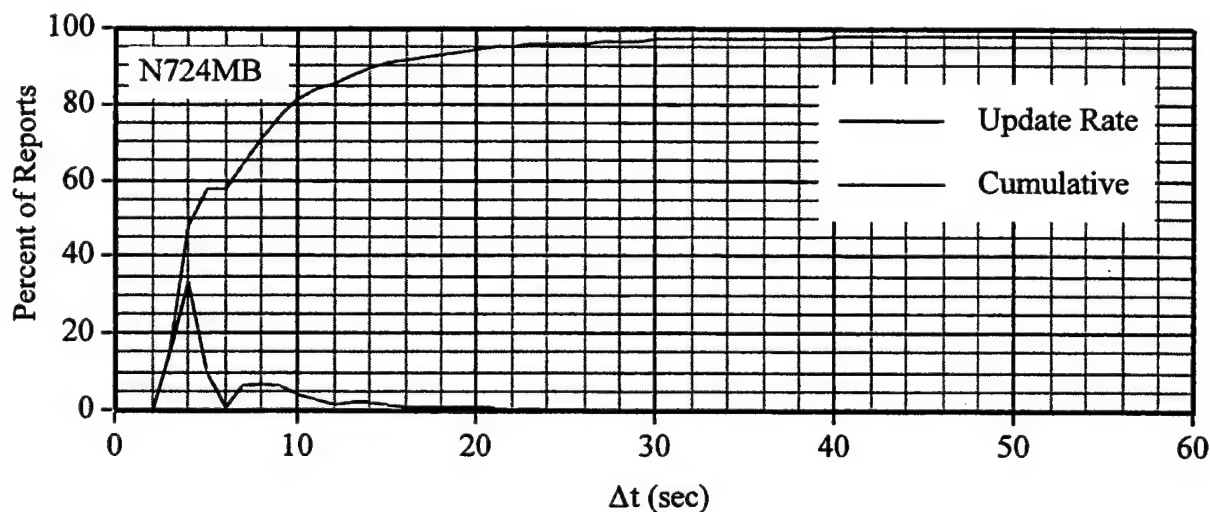
Figure 4.1 Position Report Update Rate

Several factors can affect the position report update rate. These include:
- o Blockage - terrain and buildings can block the radio signals
- o Aircraft Installation- antenna location, grounding, connectors
- o GeoNet Radio Traffic - the number of aircraft making reports

o   Non-GeoNet Radio Traffic - the GeoNet ABDS operates on the same frequency as the Civil Air Patrol (CAP) who do not use the CSMA/CA protocol

4.1.1.1 Blockage Effects

Blockage effects were examined by calculating the update rate for aircraft in an area of degraded datalink radio coverage. The most prominent area of degraded coverage was near the NBS site on the southwest side of the metropolitan area. Figures 4.2 shows the update rates for four aircraft on 7/24/96 when they were near NBS (less than 5 km) compared to when they were elsewhere on the route. The first plot shows that nominally for aircraft N724MB, 81 percent of the report intervals were 10 sec or less. However, near the NBS site, only 61 percent of the updates were 10 sec or less apart. Aircraft N7128R had a similar 20 percent degradation in coverage. Furthermore, figure 4.2 does not show the fact that within a few hundred meters of NBS, the aircraft could not be "seen" at all.
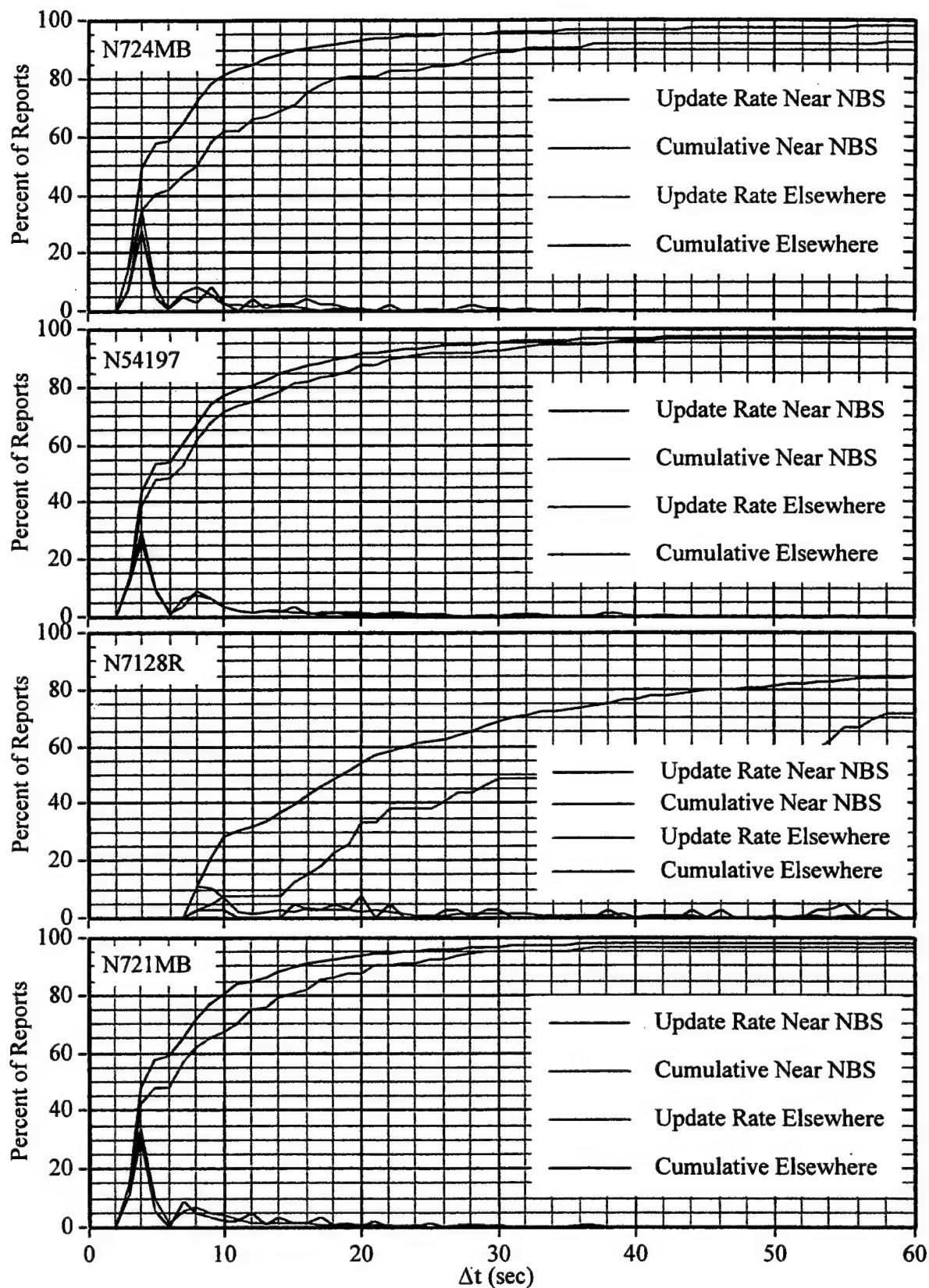
Figure 4.2 Effect of Blockage Near NBS on 7/24/96

The lack of coverage near NBS is better shown in figure 4.3 which is the track of N724MB on 7/24/96. In the figure, position reports greater than 16 sec apart are shown by a "+" and are connected by a light gray line. This indicates the uncertainty of aircraft position between widely spaced reports. The figure shows that as aircraft approach the NBS landing site, they can no longer be seen. The degraded coverage at NBS had a significant impact on the ability to automatically identify takeoffs and landings as will be discussed shortly.
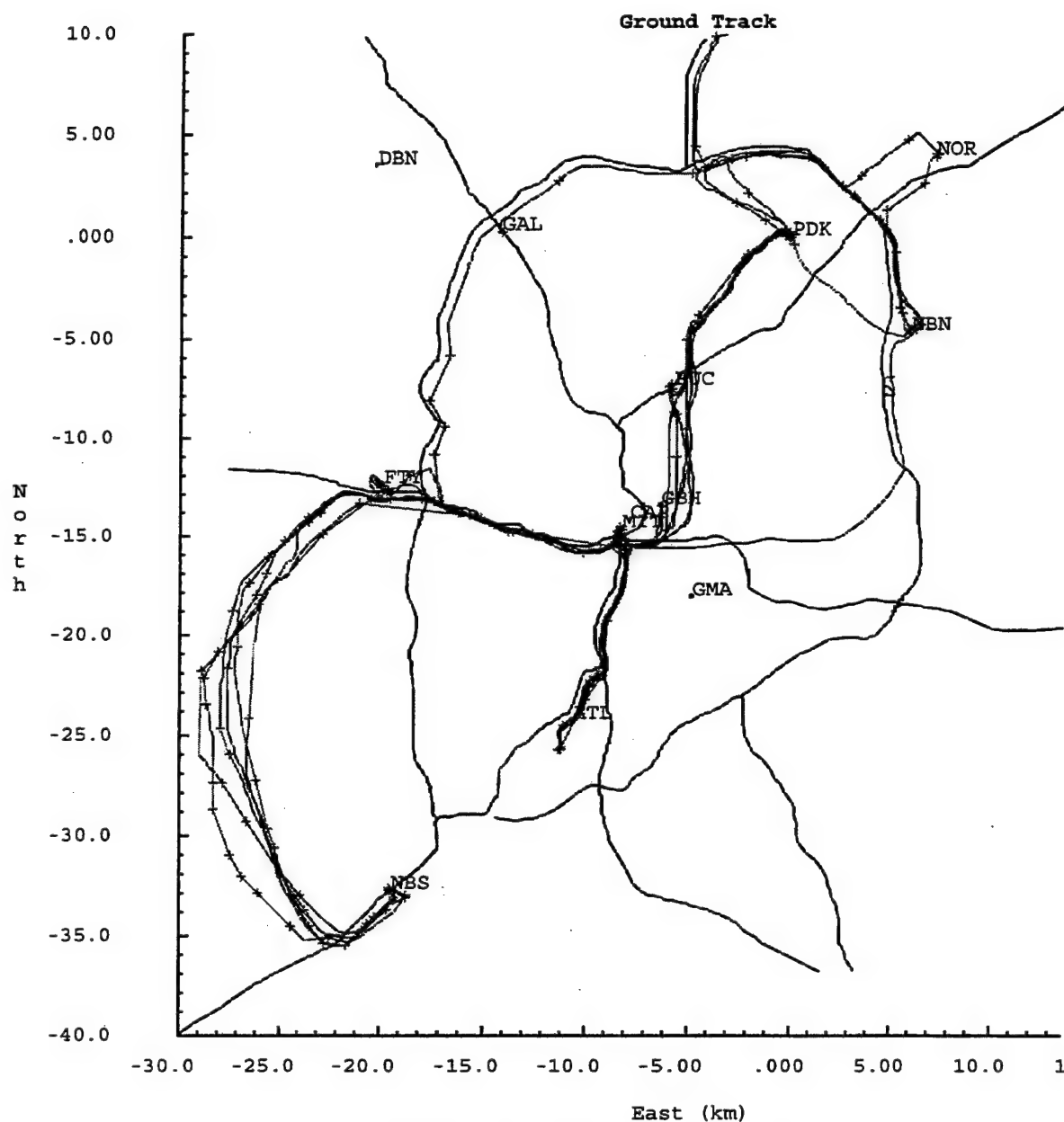
Figure 4.3 Track of N724MB on 7/24/96

4.1.1.2 Installation Effects

In an attempt to examine the effects of installation differences, update rates for different helicopters flying the same route were determined. The assumption is that aircraft flying identical routes are subject to the same blockage effects and, therefore, the differences in update rates are primarily due to installation effects. Because of the scheduling, different helicopters did not fly the same route on the same day. Consequently, this approach cannot account for variations in radio frequency traffic which can also affect the update rate. Figures 4.4 and 4.5 show a comparison for two cases. Figure 4.4 indicates that 75 percent of aircraft N54197's reports are at 10 sec or less while 70 percent of N721MB's reports are at this rate on the same route. Figure 4.5 shows a similar 8 percent difference in reporting rates of 10 sec or less for another aircraft.
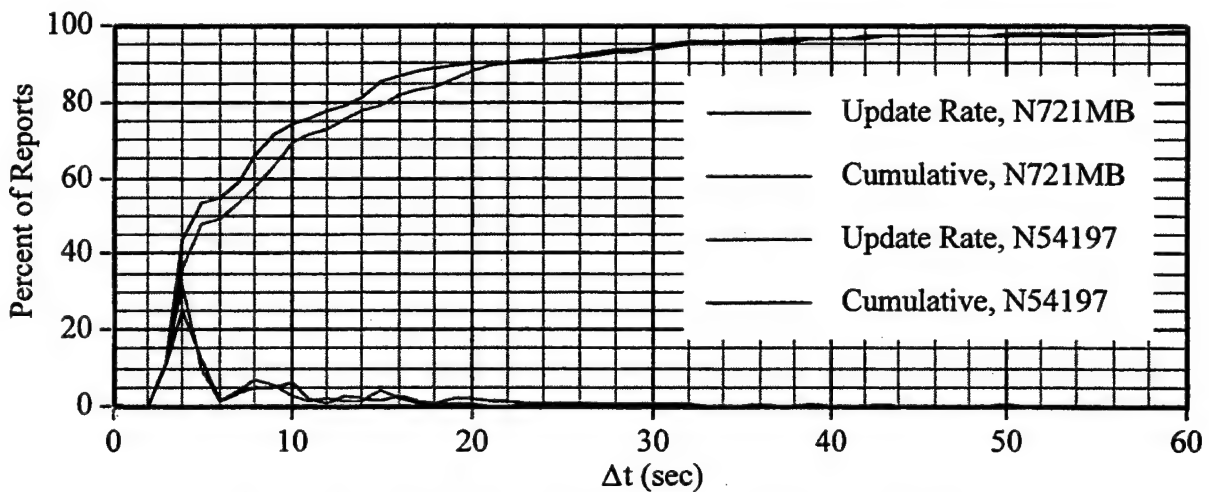
Figure 4.4 N54197 on 7/22/96 and N721MB on 7/23/96
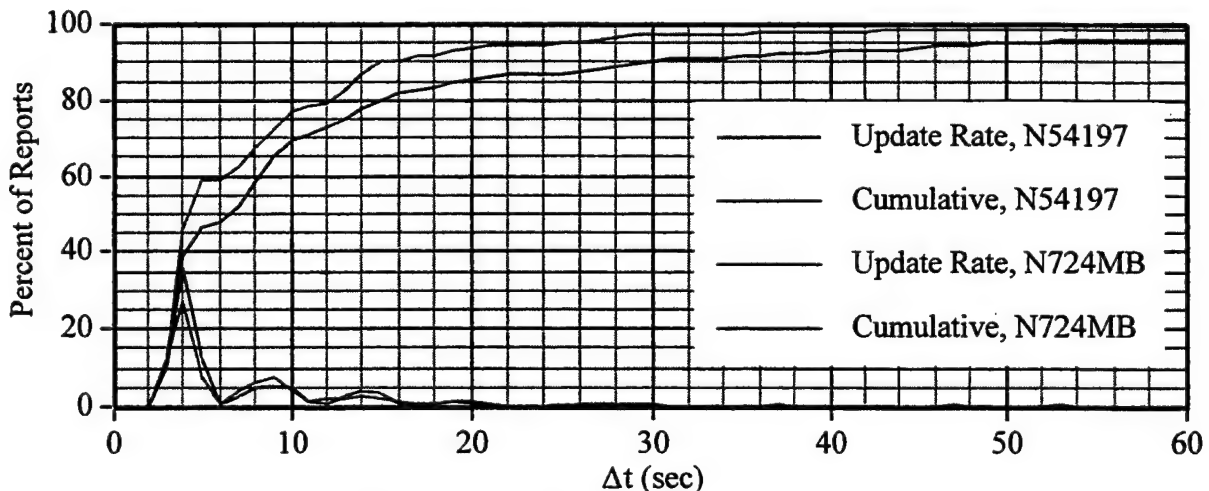
Figure 4.5 N54197 on 7/23/96 and N724MB on 7/24/96

Figure 4.6 presents an even more telling picture of the effects of installation differences. This figure shows the track of N7128R for 7/24/96. It should be pointed out that the nominal update

rate for N7128R was set to 8 sec. Comparing this figure to figure 4.3 for N724MB reveals that even though both aircraft flew similar routes, coverage of N724MB was far better than for N7128R.
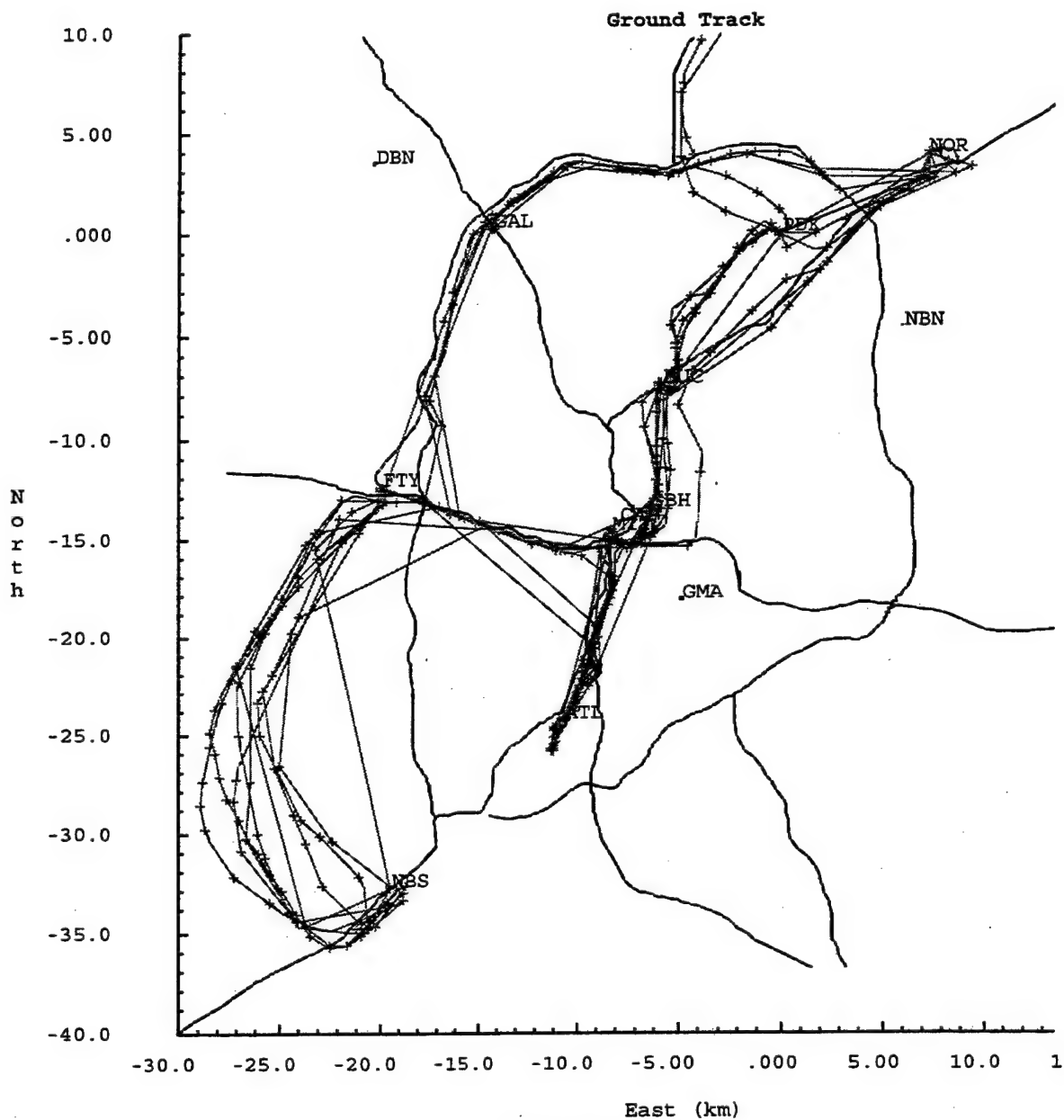
Figure 4.6 N7128R on 7/24/96

4.1.2 Database File Generation

A regime recognition algorithm was used to separate track data into individual flights by identifying takeoff and landing pairs. This allowed pertinent data from the aircraft operations to be stored in a database in an efficient manner. This process is described below.

4.1.2.1 Regime Recognition

The regime recognition algorithm breaks down the aircraft's track data into individual flights delineated by a paired takeoff and landing. It was also intended for the algorithm to identify flight segments such as climb-out, cruise, and approach. Average characteristics of each segment were to be computed including: cruise speed, cruise altitude, approach speed, approach angle, and rate of descent. However, the altitude accuracy of standard GPS was so poor as to be unusable as a flight state. Consequently, all regime recognition had to be based only on speed and distance to known landing sites. This precluded the ability to determine any altitude related characteristics such as approach angle and rate of descent.

The regime recognition algorithm functioned as follows. The "Ground" regime was initially defined as airspeed below 10 kts and distance to a known landing site less than 300 m. In some instances this criteria was too restrictive, particularly at undesignated sites. As an alternate definition for "Ground", airspeed below 15 kts only was used. Following the "Ground" regime, if the airspeed exceeded 10 kts and the range exceeded 300 m, then a "Takeoff" was declared. "Cruise" was indicated when airspeed exceed 50 kts and the range exceeded 900 m after "Takeoff". An "Approach" was declared after "Cruise" if the airspeed dropped below 80 kts and the range fell below 2700 m.

Figure 4.7 shows a sample time history of an aircraft's position, range, and speed with a coded bar indicating the identified regimes. Note that poor altitude accuracy adversely affected some of the regime recognition processing, particularly those outputs involving altitude.

Automated regime recognition suffered from several shortcomings. The lack of reliable altitude information, as pointed out previously, severely restricted the effectiveness of the algorithm. Furthermore, if a lack of coverage resulted in no position reports as the aircraft was landing, the algorithm could not correctly identify the individual flights. This was particularly true of flights to NBS where landings were scarcely ever "seen". Corrections to the automatically produced database tables were made from the pilots' logs.
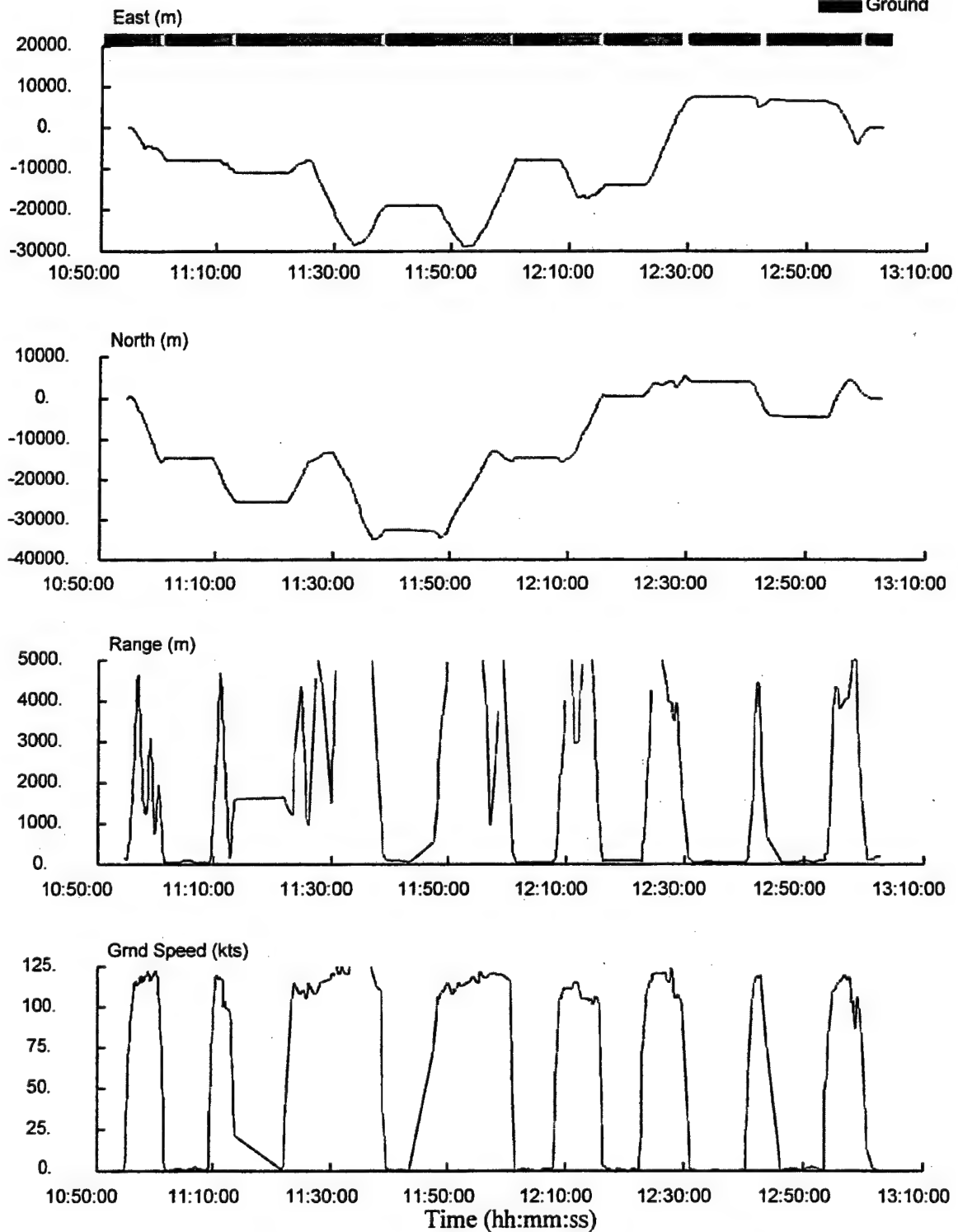
Figure 4.7 Sample Time History with Regime Recognition

4.1.2.2 <u>Corrections Using Pilots' Logs</u>

The PHI pilots who flew the Heli-STAR cargo missions kept accurate logs of their stops including the takeoff and landing times, flight time, fuel weight, and takeoff weight. Information from the pilots' logs was used to correct the automatically generated database files. These files are stored in the Oracle database system described below.

4.1.3 <u>Database Management System</u>

Data collected during the Atlanta Short-Haul Transportation demonstration is stored in electronic form using the ORACLE relational database management system (RDBMS). In a relational database, all information is stored in tables related to each other via columns. A relational database can be queried for information in various tables simultaneously using common columns of information in these tables. The following subsections describe the Heli-STAR database and the information accessing (Standard Query Language) command structure. Sample query results are provided to illustrate the process.

4.1.3.1 <u>Database Description</u>

Heli-STAR database is made up of 81 data files. All of these data files reside on an HP9000-735 server as ASCII text format and are accessed with ORACLE version 7.0.16. Out of the 81 data files, 73 are flight data files - one for each helicopter for each twenty four hour period flown. Five are cargo data files - each one containing information for the entire demonstration period on aircraft, flight numbers, itineraries, payload, and shippers. Two data files contain all the pilot and site information.

All information in the Heli-STAR database is explicitly presented as two dimensional tables. Every table is defined with a table name and set of columns. Each column is given a column name, data type, and width. Data items are accessible by specifying a table name, column name, and row identifying the location of the data point being sought in a two dimensional table. Any null values in the table are valid data types representing missing information. A description of Heli-STAR database tables follows.

flt table
The flight (**flt**) table contains data on all of the helicopter cargo operations and a few others. Flight operations for the following helicopters are included in the flt table:
N15AH   N38   N3893   N5419   N624M
N7128   N721M   N724M   N8183   N967
Operations are covered from 7-19-96 to 8-2-96 excluding weekend operations (7-20, 7-21, & 7-28).

The information in the flt table includes the flight date, the route, aircraft tail number, gross weight, takeoff and landing times, flight origin and destination, average cruise speed, and flight time. A unique flight number is assigned to each flight on the basis of the aircraft tail number, flight date, and takeoff time. This table allows the analysis of flight activity by aircraft tail

number, helipad location, time of day, etc. Section 4.1.3.3 illustrates the data querying and utilization process.

ac_specification table
The aircraft specification (**ac_specification**) table contains helicopter data such as tail number, helicopter base designations (aircraft type), physical characteristics, performance capabilities, payload capacities, data link serial number, and operator. Data in the ac_specification table is linked to the flt table through aircraft tail number.

sites table
The **sites** table contains helipad related information such as latitude/longitude coordinates, site type (such as roof top, parking lot, etc.), surface type, and area. Data in this table is linked to the flight data through the site_id which corresponds to either the origin or destination in the flt table. This permits the determination of activity based on location, surface type, or site type of a helipad.

pilots table
The Heli-STAR database was designed with provisions for adding any pilot related information to the database later on. The **pilots** table is set up to accommodate pilot data such as type of certification, certification for instruments, certification for number of engines, engine type, and flight hours. At the writing of this report, no such information was available or loaded into the database. In addition, pilot names for each flight have not been transferred from the pilots' log into a column in the flt table. This step is necessary to correlate individual pilots with flight tracks in order to study the relation between a pilot's certification and how well he conformed to the route or the approach.

itinerary table
The **itinerary** table contains estimated and actual times of arrival and departure for cargo flights. Most of the operations data was developed from the cargo operations scheduling databases and spreadsheets. The itinerary data is linked to the flight data through the unique flight number and to site table by origin and destination. This information can be used in determining the effectiveness of schedules by comparing planned times with actual times.

payload table
The **payload** table contains information relating to Heli-STAR cargo operations. This data is an output of the Genesis cargo tracking software and includes payload weight and volume, number of items, shipper identification, and receiving/loading/unloading times. This table is linked to the shipper table by shipper ID and to the payload tag table by tag number. This table lists information that will help determine how much time was spent in actual flight for comparisons to the time spent loading and unloading packages. Comparison of cargo activity of shippers and helicopters can be determined from this data. Total cargo weights and volumes can also be calculated.

shippers table

The **shipper** table contains a summary of shipper information such as type of operation: banking, priority package delivery, newspaper, etc. This information can be used to determine what type of industries might take advantage of helicopter transportation.

tags table

The **tags** table contains all the cargo tag numbers with departure and arrival flight numbers, and tail numbers. This information was a direct output of the Genesis cargo tracking software. Data in this table is linked to the flight data by flt number in the flt table and to the shipper data and payload data by tag ID and shipper ID.

ac_id table

The aircraft identification (**ac_id**) table was created to accommodate some of the relational database concepts and queries. All of the flight information contained in the flts table identifies each flight number by unique flight number. All of the cargo information contained in the payload and tags tables is identified by a different flight number assigned by cargo operations. In order to query the two different types of information together, this table was created to correlate the two types of flight numbers.

Figure 4.8 below illustrates the structure and information contained in the tables and notes the relationship between various columns by color coded names. These related columns are heavily used when querying the database on multiple tables. Most often information from one table is used as criteria for search on another table. Section 4.1.3.2 illustrates the data acquisition process.

ac_specification

TAIL_NO
AC_TYPE
BASE_DES
RADIUS
MAX_GW
MAX_RANGE
CRUISE_SPEED
PAYLOAD_VOL
PAYLOAD_WT
MR_BLADES
TR_BLADES
NAV_SYS
DATA_LINK_ID
OPERATOR

flt

UNIVERSAL_FLTNO
GW
ROUTE
FLT_NO
FLT_DATE
TAIL_NO
TO_TIME
LD_TIME
FLT_TIME
SPEED
ALT
ORIGIN
DEST
APRCH_SPD
APRCH_ROD
APRCH_ANG

sites

SITE_ID
COMMENTS
LAT
LON
ALT
AREA
SURFACE_TYPE
SITE_TYPE
COLOR

flt_nos

TAG_ID
ARR_FLTNO
DEP_FLTNO

pilots

PILOT_NAME
FLT_HRS
CERT
CERT_INST
CERT_ENG#
ENG_TYPE
CERT_IFR

payload

TAG_ID
SHIPPER
CPM
WEIGHT
VOLUME
NO_OF_ITEMS
RECVED_TIME
LOAD_TIME
UNLOAD_TIME
DISP_TIME
FLT_DATE

ac_id

AC_ID
TAIL_NO
UNIVERSAL_FLTNO

tags

TAIL_NO
TAG_ID
ARR_FLTNO
DEP_FLTNO
UNIVERSALTNO

itenerary

UNIVERSAL_FLTNO
ORIGIN
DEST
FLT_NO
ETD
ATD
ETA
ATA

shippers

SHIPPER
TYPE

* *color coded columns relate various tabulated data*

Figure 4.8 Heli-STAR Database Tables

4.1.3.2 Sample Queries And Data

At the heart of ORACLE RDBMS is Standard Query Language (SQL). As mentioned earlier all of the data in the Heli-STAR database is accessible by specifying a table, column name, and row location. Queries are statements that retrieve data in any combination, expression, or order from the relational database. Below are some queries carried out on the existing Heli-STAR database with sample outputs and a graphical presentation of the results.

This first example demonstrates how to find which aircraft used in the cargo operations were of a particular type (say, Bell 412). The ac_specification table is queried by specifying the base designation and requesting the corresponding tail numbers:

```
SQL> select tail_no, base_des from ac_specification where
 2  base_des like '%412%';
```

Results:

TAIL_NO	BASE_DES
N7128R	412
N3893N	412

The following is an example of using two tables in conjunction to get the desired information. This example accesses data in two tables (payload and tags) to determine payload carried by each helicopter.

```
SQL> run
 1  select tags.tail_no, payload.tag_id, payload.weight
 2  from tags, payload
 3  where tags.tag_id=payload.tag_id
 4*
```

Results:

TAIL_NO	TAG_ID	WEIGHT
N967MB	5000747	5
N721MB	6000410	30
N721MB	6000411	30
N721MB	6000413	30
N721MB	6000415	28
N967MB	10000347	2
N7128R	10000369	43
N7128R	10000380	15

The following figures were plotted from the output of the above query.

PAYLOAD DISTRIBUTION

N54197
13%

N967MB
10%

N3893N
36%

N724MB
12%

N721MB
1% N624MB
7%

N7128R
21%
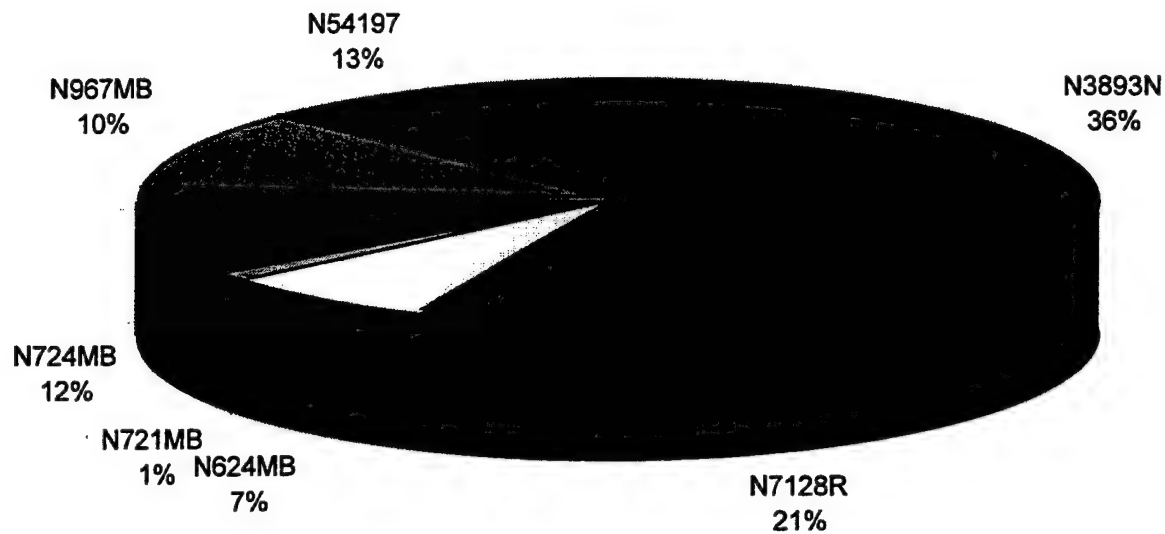
Figure 4.9 Payload Distribution by Aircraft Tail Number

PAYLOAD DISTRIBUTION BO-105 VS. 412

BO 105
43%

412
57%
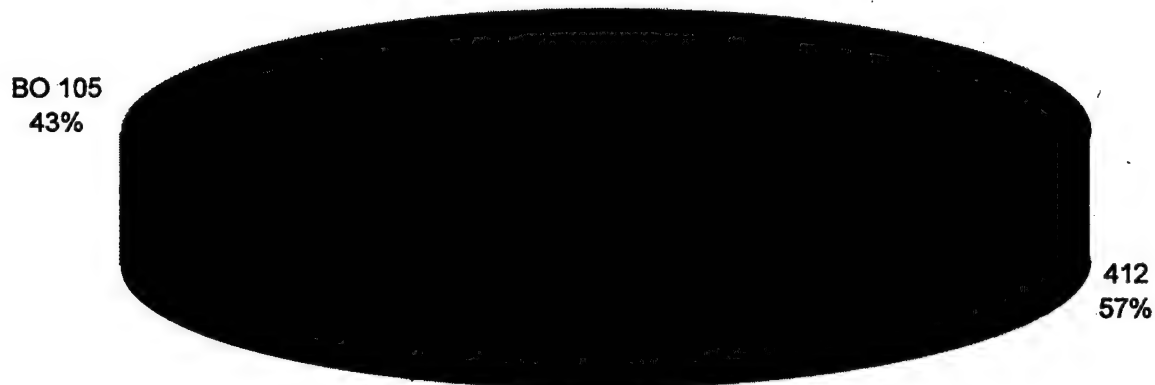
Figure 4.10 Payload Distribution by Aircraft Type

Following query is an example of collecting the number of flights by the location of the helipad.

SQL> select origin, flt_no, to_time from flt where origin like '%ATL%';

Results:

```
ORIGIN FLT_NO          TO_TIME
------ ------------------ --------
ATL   N721M960719074309 7:43:09
ATL   N721M960719103509 10:35:09
ATL   N8183960719122039 12:20:39
ATL   N15AH960722172204 17:22:04
ATL   N3893960722061335 6:13:35
ATL   N3893960722101701 10:17:01
ATL   N3893960722130000 13:00:00
ATL   N3893960722153829 15:38:29
ATL   N3893960722182418 18:24:18
```

ATL ORIGINATING FLIGHTS
SORTED BY TIME OF DAY
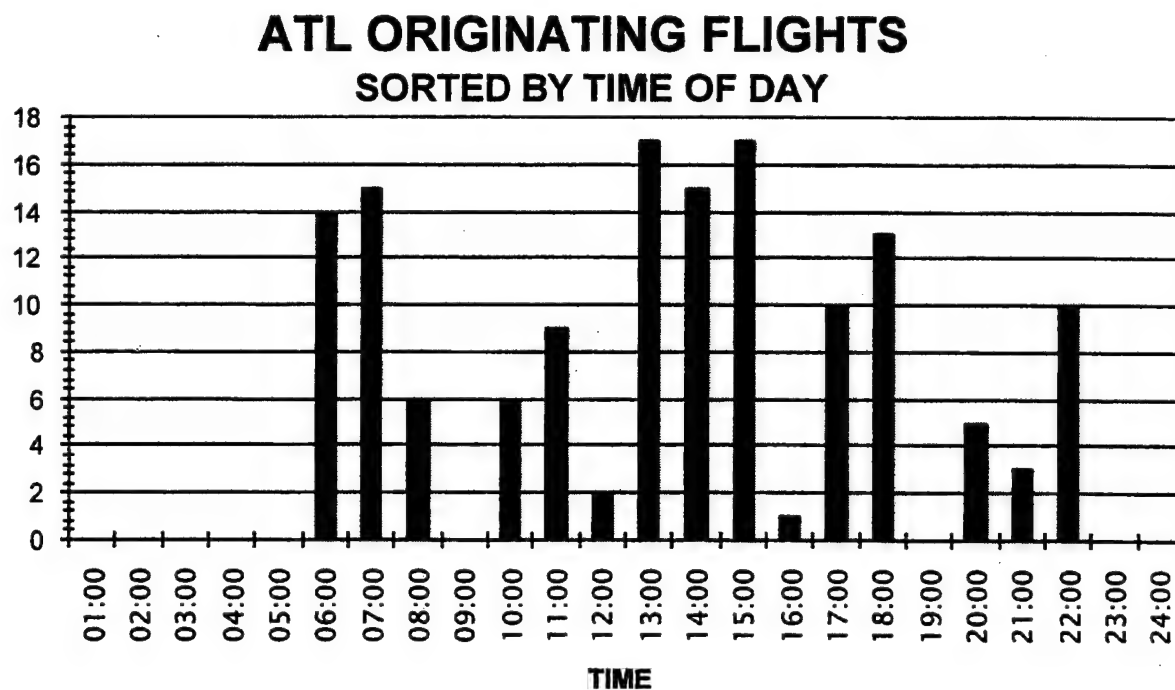
Figure 4.11 Flights Out of ATL by Time of Day

BUC ORIGINATING FLIGHTS
SORTED BY TIME OF DAY
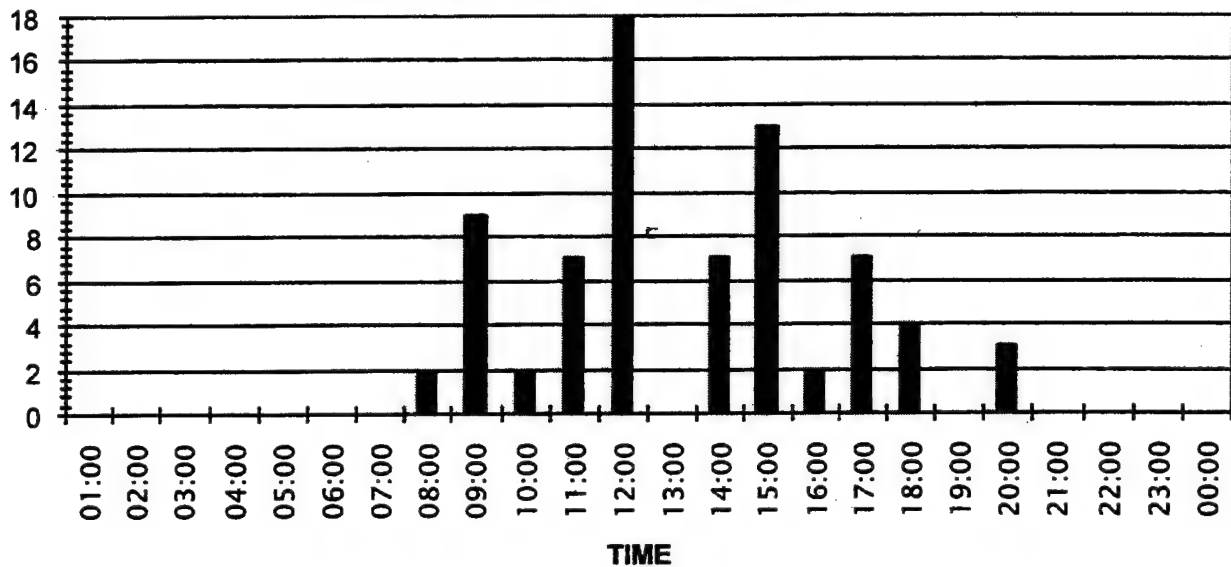
Figure 4.12 Flights Out of BUC by Time of Day

FTY ORIGINATING FLIGHTS
SORTED BY TIME OF DAY
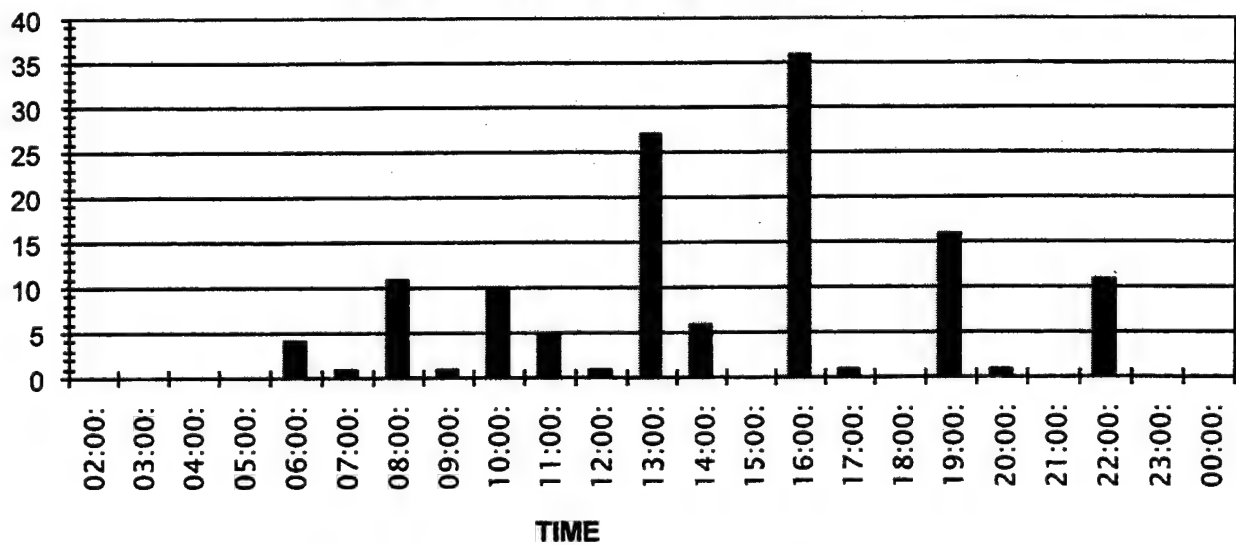
Figure 4.13 Flights Out of FTY by Time of Day

Note: The above data was also used to determine flight activity for each helipad location.

FLIGHT ACTIVITY BY LOCATION
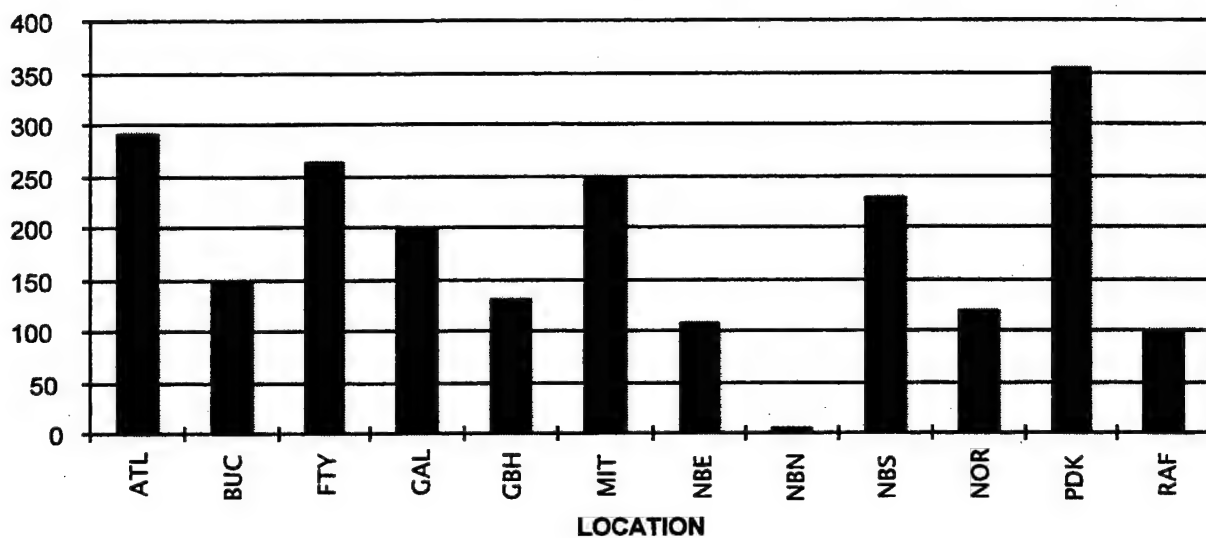
Figure 4.14 Flight Activity by Location

CARGO DISTRIBUTION BY LOCATION
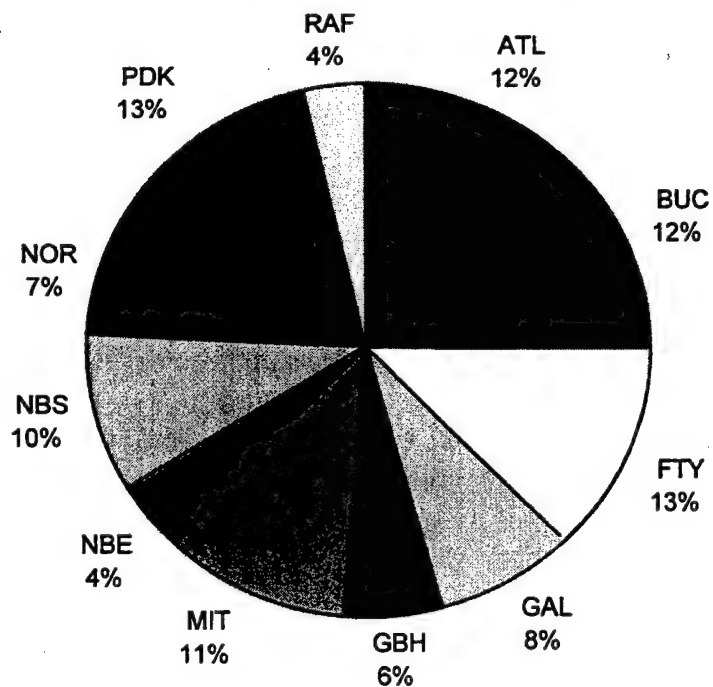
Figure 4.15 Cargo Distribution by Location

4.1.3.3 Database Utilization

The Heli-STAR relational database offers easy access to flight and cargo data. This database offers flexibility of data modeling and reduces data storage and redundancy for any future analysis with Heli-STAR statistics. The database provides concise access to essential information which can be used for economical studies to analyze an urban aerial transportation infrastructure.

Heli-STAR database is portable to other ORACLE servers. Moreover, any of information contained in the data files can be transported to any platform and similar databases can be constructed using different database applications.

4.1.4 Track Observations

Ground track data was highly useful in determining where aircraft flew in relation to the routes, roadways, and neighborhoods. One of the main concerns from a "fly neighborly" perspective is that helicopters stay on routes that keep them away from noise sensitive areas. The following sections show that two factors influenced the helicopter flight paths in the metropolitan area: the presence of route landmarks and the type of operation (i.e. commercial or law enforcement).

4.1.4.1 Effects of Visual Cues on Track Dispersion

Figure 4.16 shows the tracks of four aircraft on 7/24/96. Note that on the portion of the routes overlaying the interstate highways, the tracks are tightly grouped together. However, on the southwest side, the route is indicated by few landmarks. Consequently, the aircraft tracks are fairly widely dispersed. This dispersion can be measured by taking a cut across the tracks at given Y coordinate (25 km south of PDK) and determining the mean and standard deviation of the X (East/West) coordinate. Track dispersion was measured in a similar manner on the East/West tracks overlaying I-20 at 14 km west of PDK and on the North/South tracks through midtown at 11 km south of PDK. Table 4.3 presents the standard deviation at each location for a five day period during the first week of operation. Figure 4.17 shows for each location the density function assuming a normal distribution.

The data in table 4.3 quantitatively verify the previous observation that for aircraft operating under VFR, fewer visual cues result in larger track dispersion. During the Heli-STAR demonstration, no significant effort was made to use GPS for en route guidance to the precision of an IFR operation. Consequently, conclusions drawn from data in table 4.3 apply to VFR operations only.
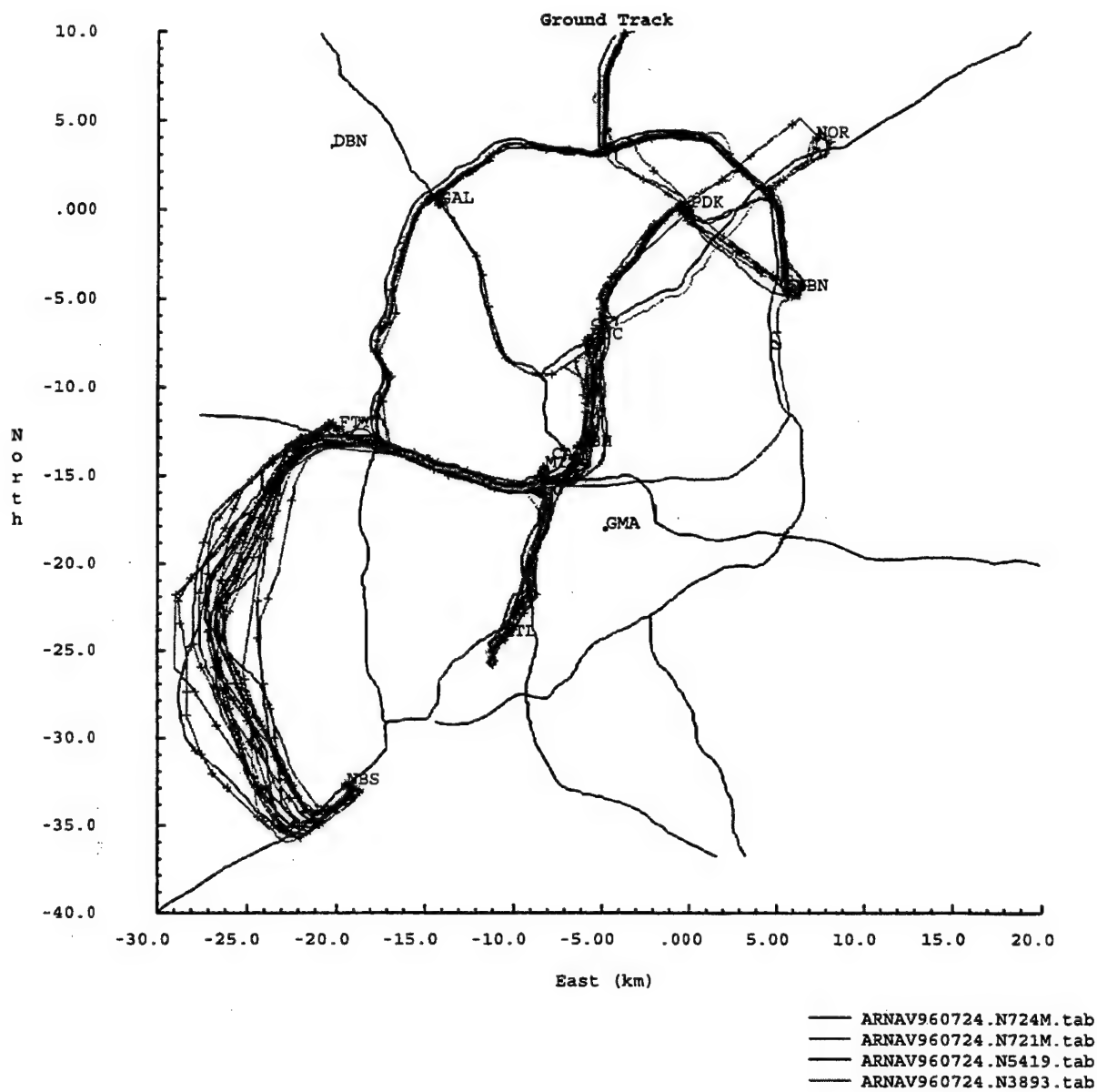
Figure 4.16 Tracks on 7/24/96

Table 4.3 Track Dispersion Standard Deviation (Km)

Date	SouthWest	MidTown	West I-20
7/22/96	1.39	0.46	0.13
7/23/96	0.54	0.38	0.21
7/24/96	1.22	0.47	0.11
7/25/96	0.92	0.39	0.09
7/26/96	1.24	1.01	0.14
Total	1.17	0.55	0.15

4- 21

Probability Density Function (PDF)
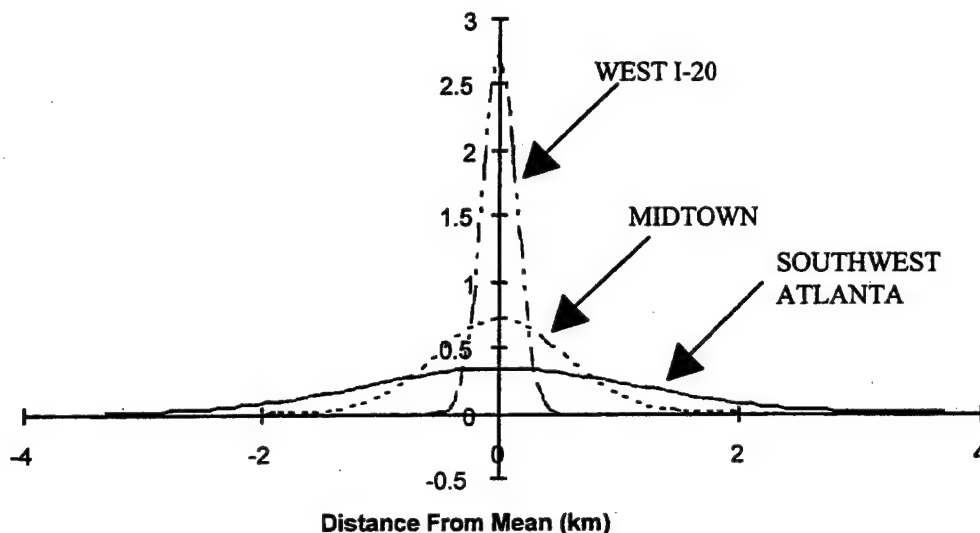
Figure 4.17 Probability Density Function for Track Dispersion

4.1.4.2 Effects of Operations on Tracks

Prior to and during the Olympic Games, law enforcement aircraft were quite active. Obviously the nature of law enforcement operations is quite different from cargo hauling and this is quite evident in the tracks of law enforcement aircraft. Figure 4.18 shows the tracks for three law enforcement aircraft from 7/1//96. In contrast to the constrained tracks shown in figure 4.16 for the Heli-STAR aircraft, law enforcement aircraft operate over a much larger area. In fact, it was found during the Heli-STAR demonstration that citizen complaints of helicopter noise were due to law enforcement activities and not the Heli-STAR cargo operations.

4.2 ACOUSTIC TESTS

Figure 4.19 shows the ground track of the flight pattern used for the acoustic footprint mapping test while figure 4.20 shows a typical approach. These flight tests required an accurate tracking of the helicopter with time correlation to the sound pressure recordings. The following subsections describe the steps that were taken to improve the accuracy of the GPS position reports for the footprint acoustic tests.
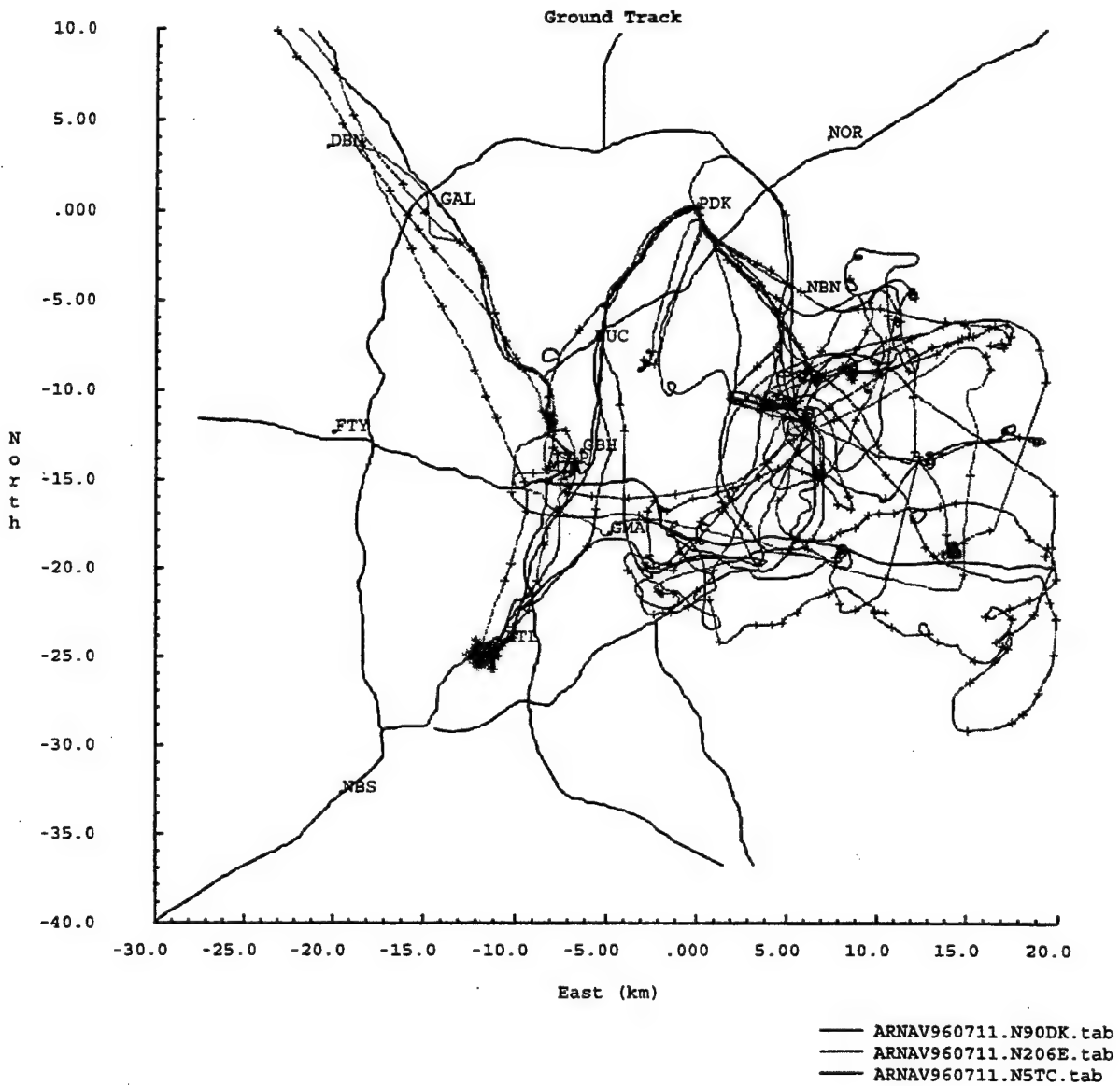
Figure 4.18 Example of Law Enforcement Helicopter Activity
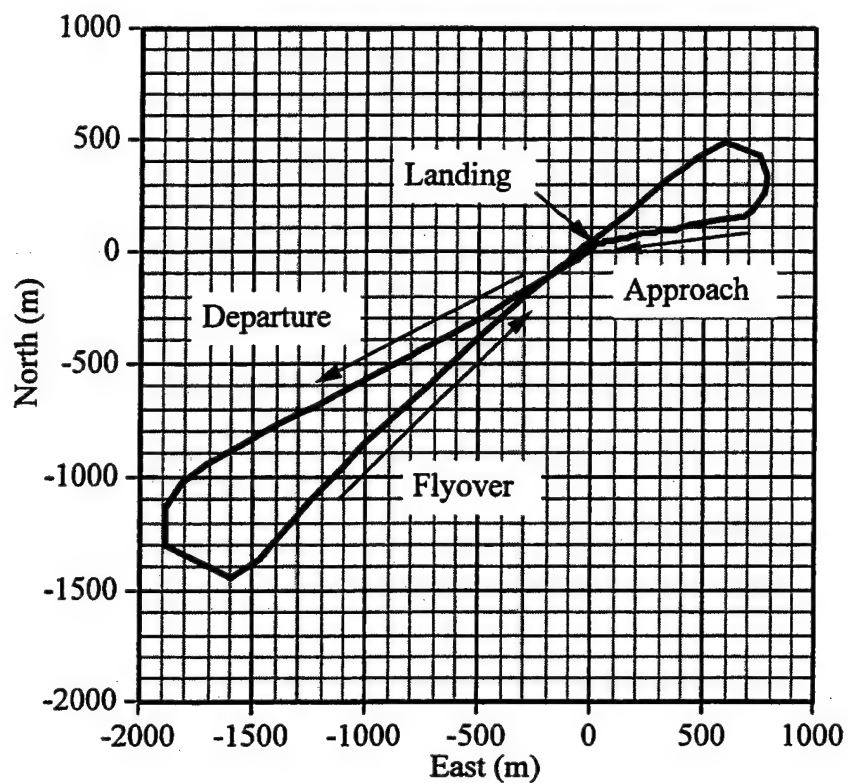
Figure 4.19 Typical Ground Track of Acoustic Footprint Mapping Test
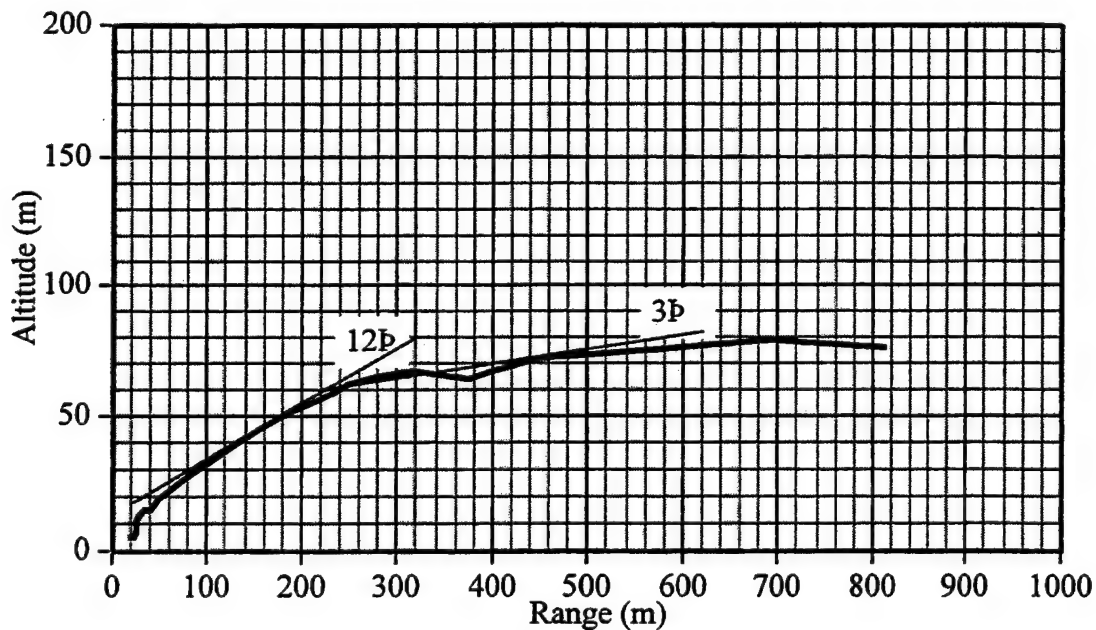
Figure 4.20 Typical Approach for Acoustic Footprint Mapping Test

4.2.1 Altitude Correction With Portable ARNAV Unit

A portable GeoLink ground station was used to record the test aircraft's position at the test site. The portable unit which was stationary at about 30 m (100 ft) south of the helipad also recorded its own position. The ground unit's position report was used in a differential correction to the aircraft's position report. This, of course, assumed that the ground unit and the aircraft's unit used to the same set of satellites for a position solution. Improvements in altitude accuracy were the chief concern in this case.

Figures 4.21 through 4.25 show the altitude time histories for the five test cards that were flown. Time on the horizontal axis is in total seconds from midnight so that the scale is linear. Each figure shows the raw GPS altitude report for the aircraft and the ground station, and the difference between the two. The differential correction makes the takeoff and landing cycles much clearer for the most part; however, the correction is not entirely sufficient. In some cases the data indicates that the aircraft landed 125 m (410 ft) below the ground station or 75 m (246 ft) above it.
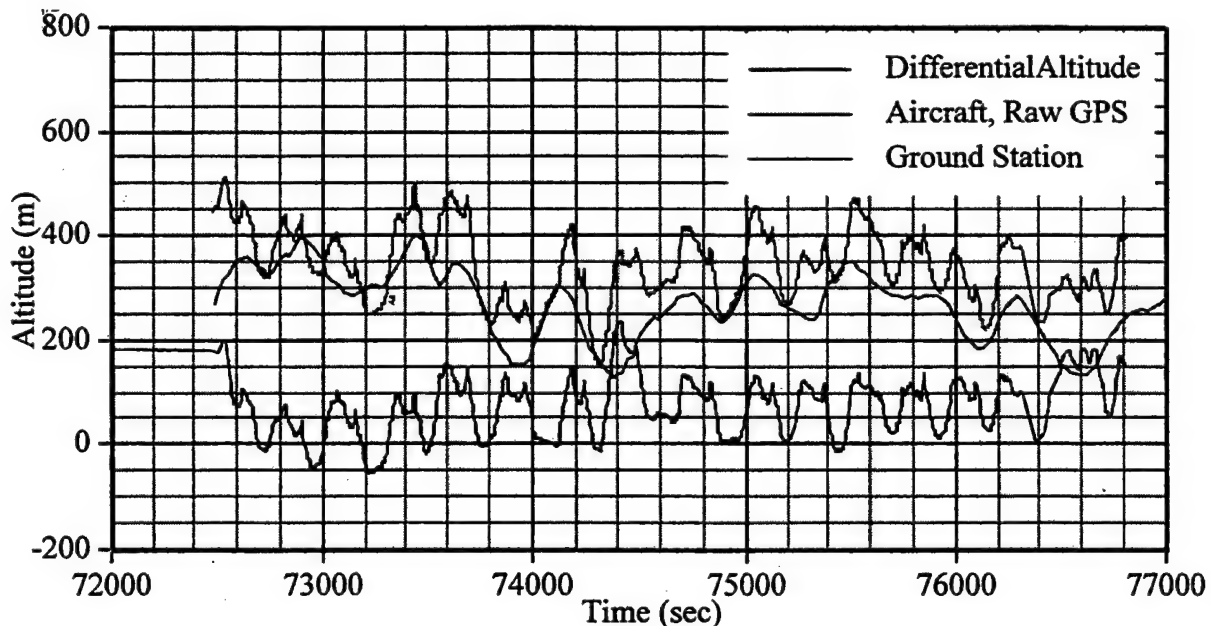
Figure 4.21 Card A Differential Altitude Correction

4- 25
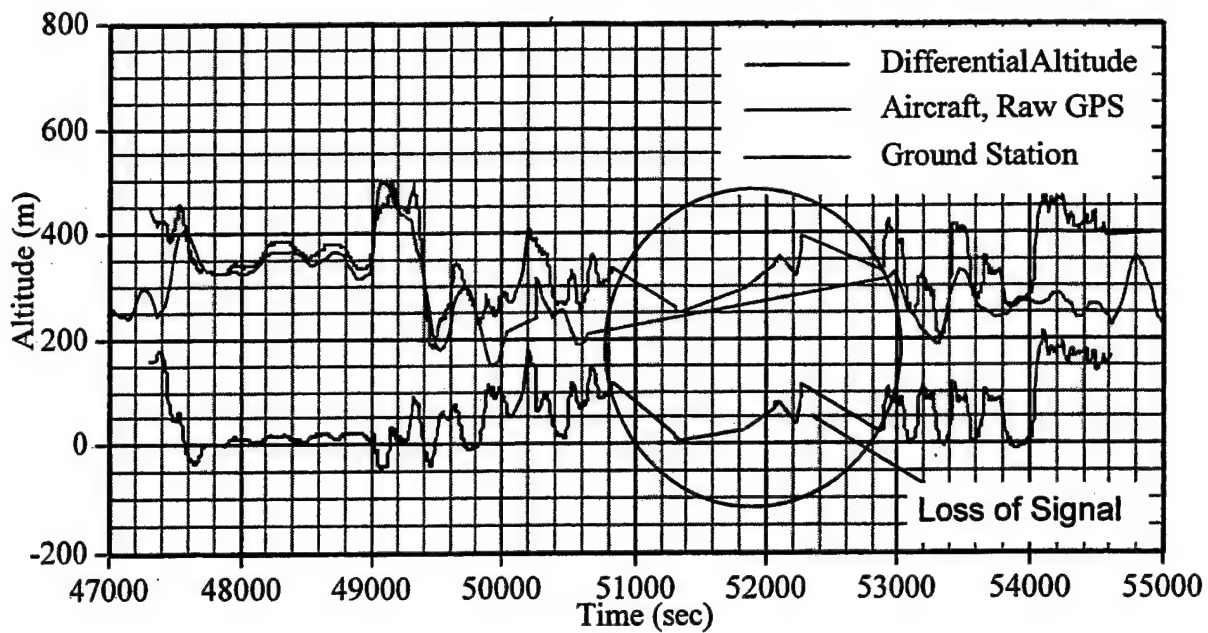
Figure 4.22 Card B Differential Altitude Correction
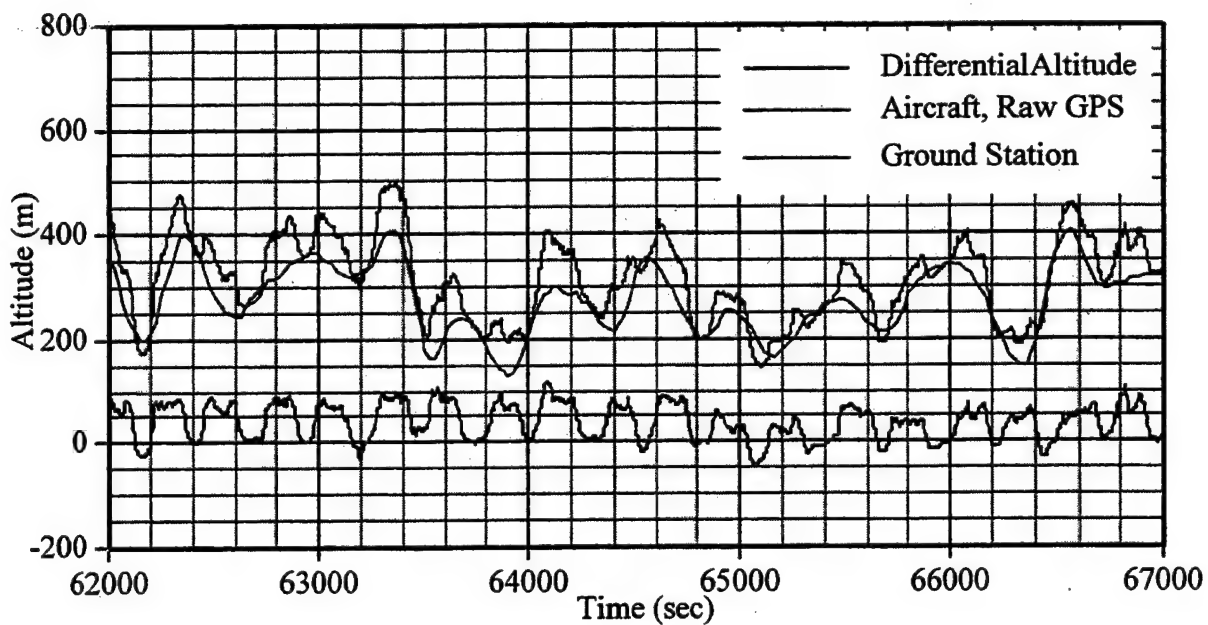
Figure 4.23 Card C Differential Altitude Correction
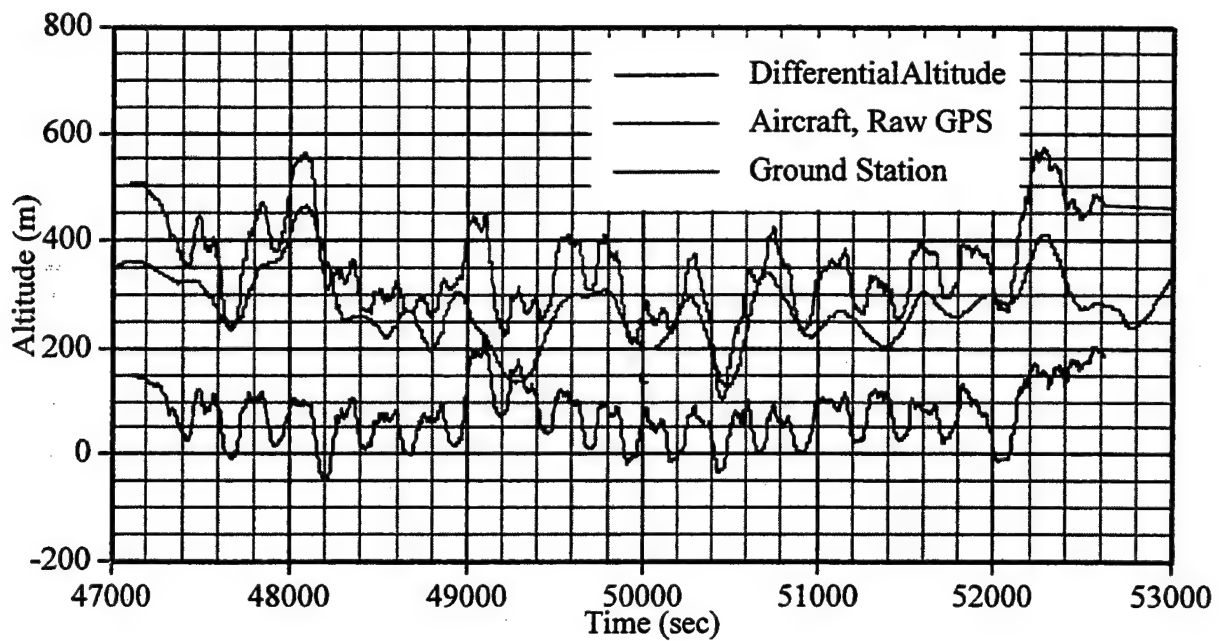
Figure 4.24 Card D Differential Altitude Correction
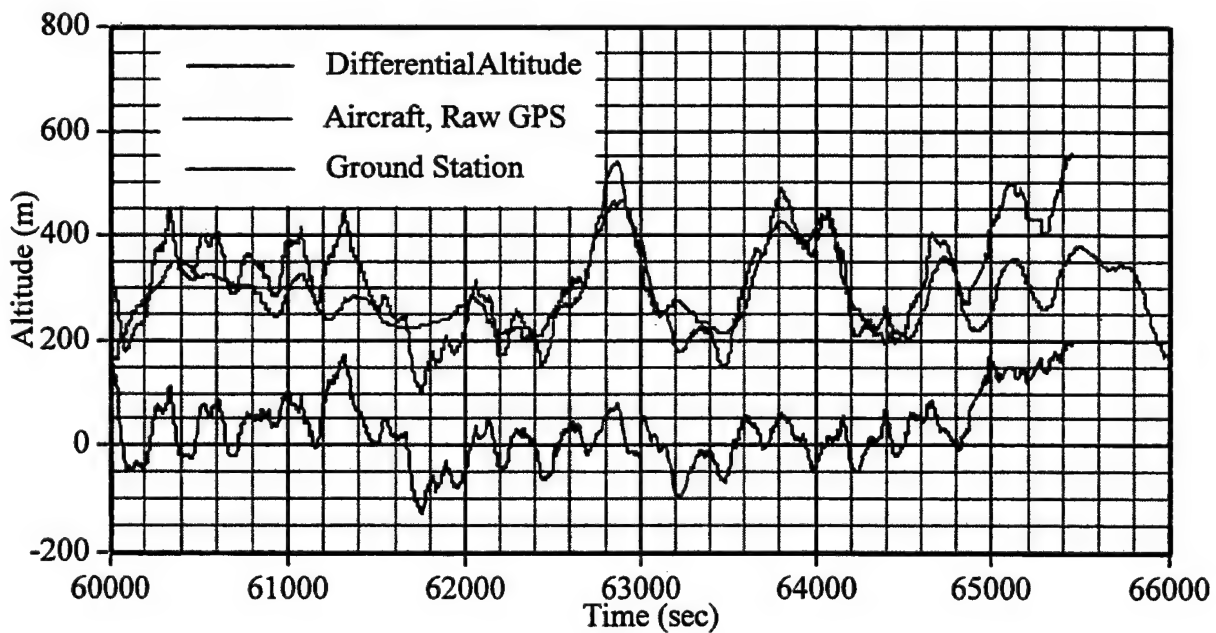
Figure 4.25 Card E Differential Altitude Correction

Since the altitude of the aircraft on the ground was known to be 0 m relative to the ground station, the differential altitude data was shifted to make it 0 m at the landings. This was done by

adding a linear correction to the data between two consecutive landings. Figure 4.26 shows an example of the shifted differential altitude for Card A.
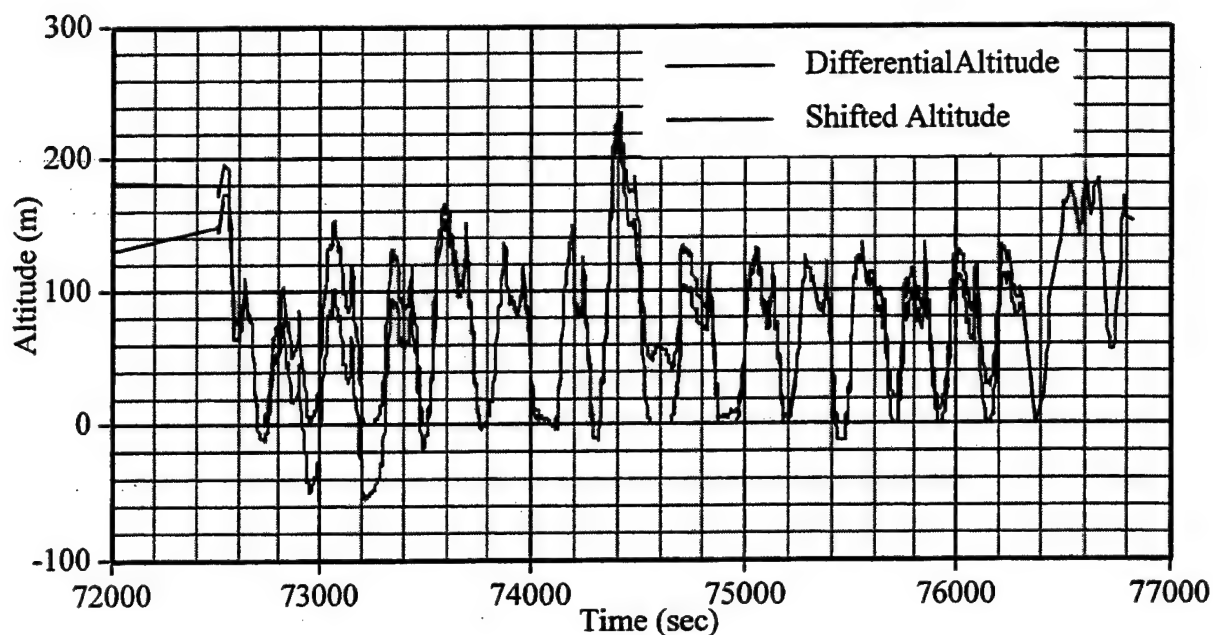
Figure 4.26 Card A Shifted Differential Altitude

4.2.2 Altitude Correction With PDK Radar

Radar data obtained from PDK airport was used to correct the fly-over portion of the differential altitude. This was done by scaling the altitude data between landings to match the radar data above 80 m (260 ft) above ground level (see figure 4.27-4.31).
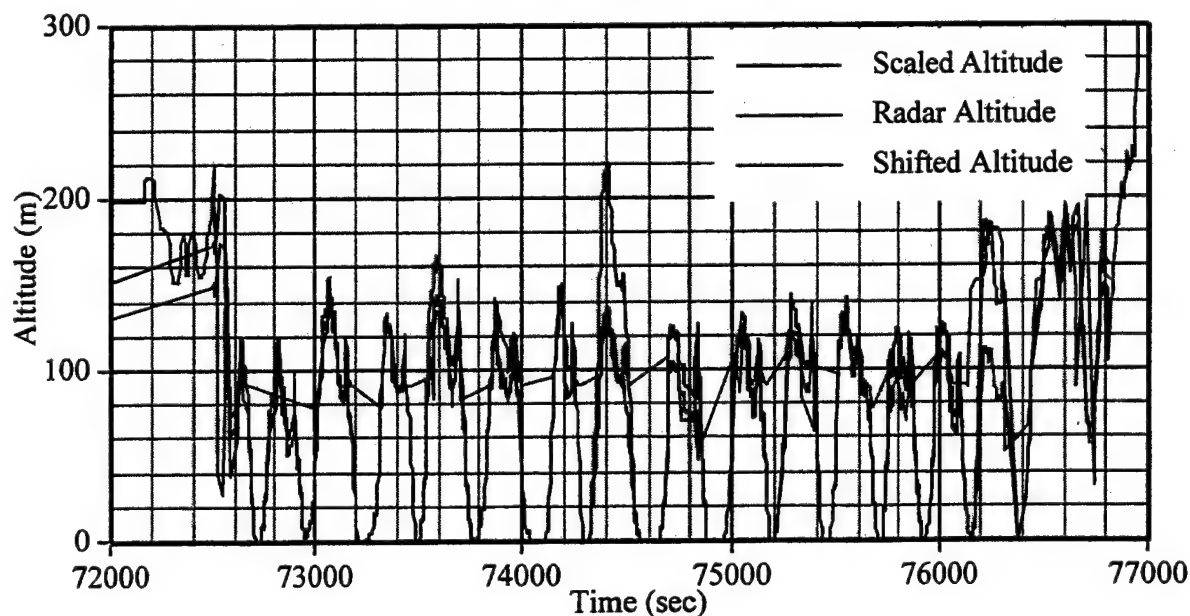
Figure 4.27 Card A Scaled and Shifted Differential Altitude
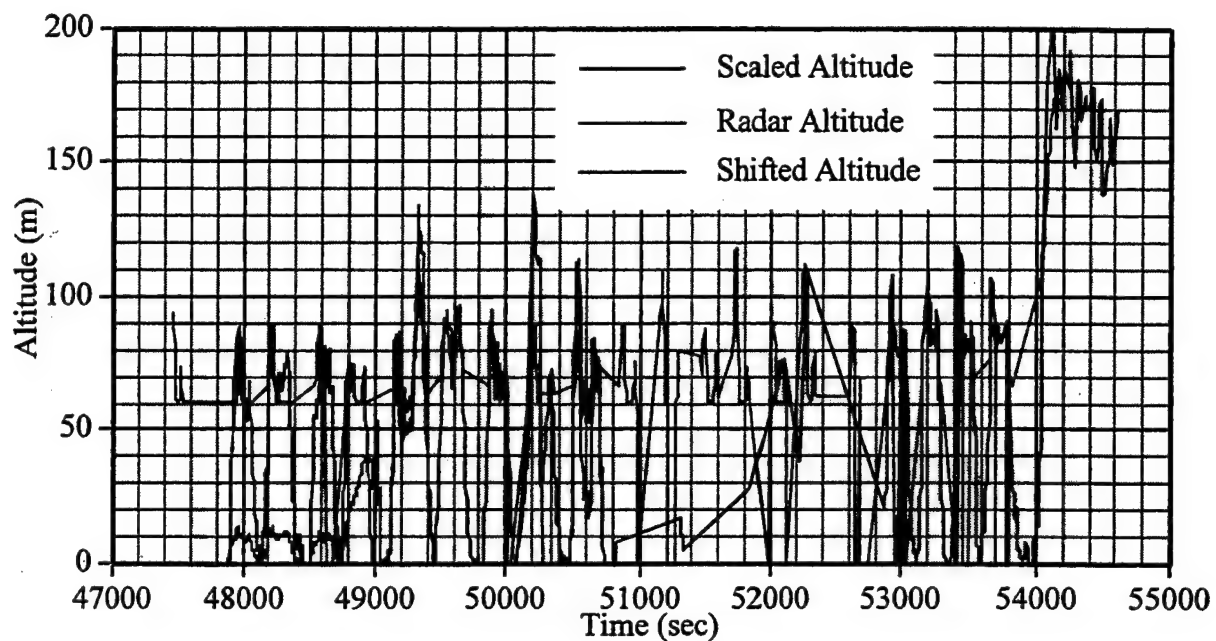
Figure 4.28 Card B Scaled and Shifted Differential Altitude
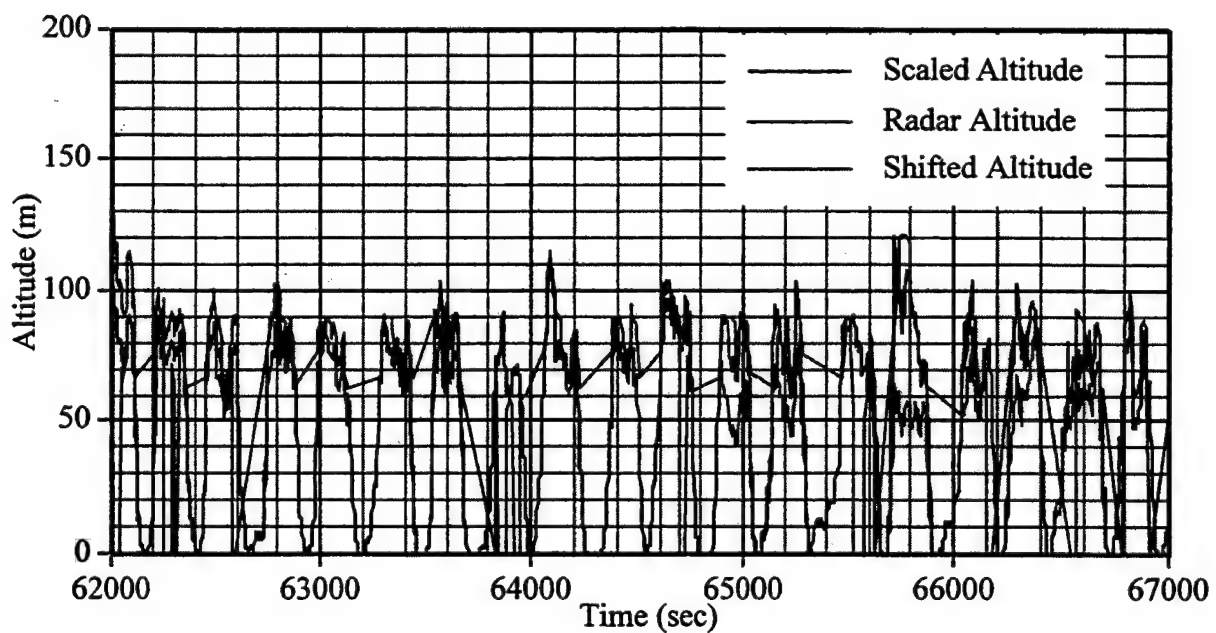
Figure 4.29 Card C Scaled and Shifted Differential Altitude
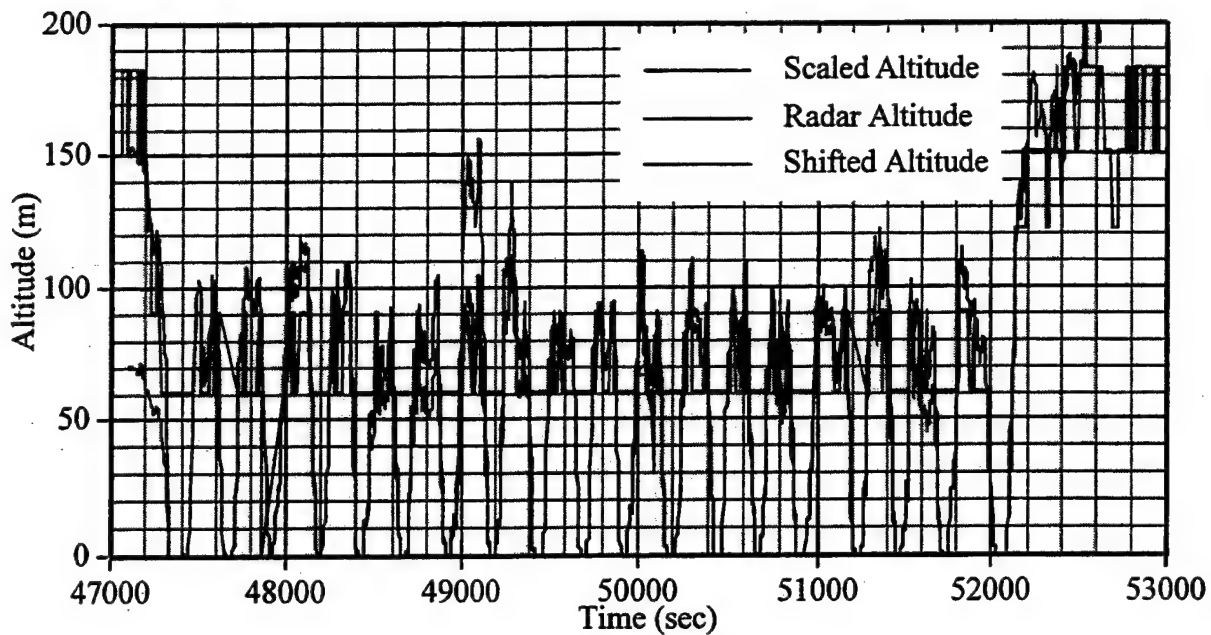
Figure 4.30 Card D Scaled and Shifted Differential Altitude
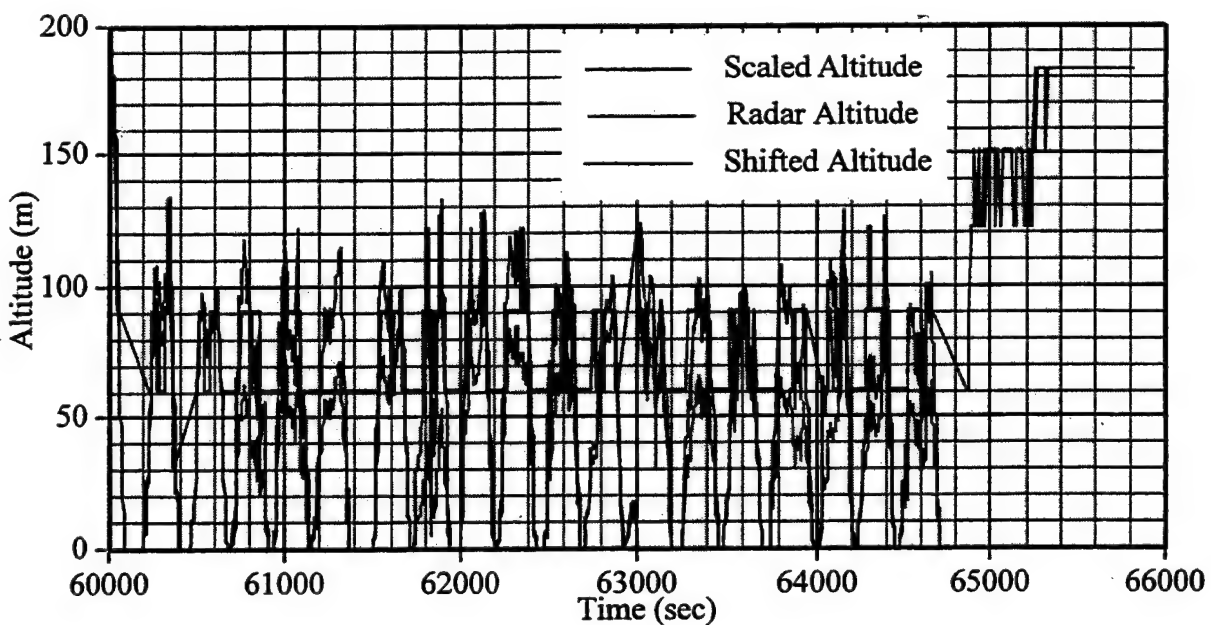
Figure 4.31 Card E Scaled and Shifted Differential Altitude

4.2.3 Position Correction With Portable ARNAV Unit

Aircraft position data was also differentially corrected using the portable ground station as a reference. Figures 4.32 through 4.41 show the difference in the ground tracks between the raw position reports and the differentially corrected position.
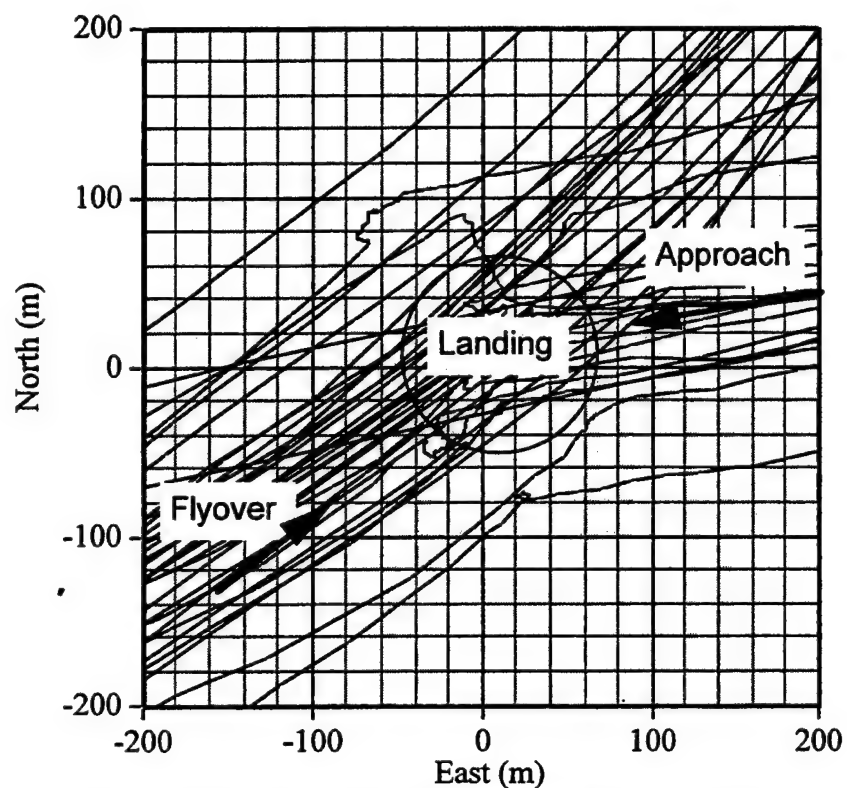
Figure 4.32 Card A Uncorrected GPS Ground Tracks
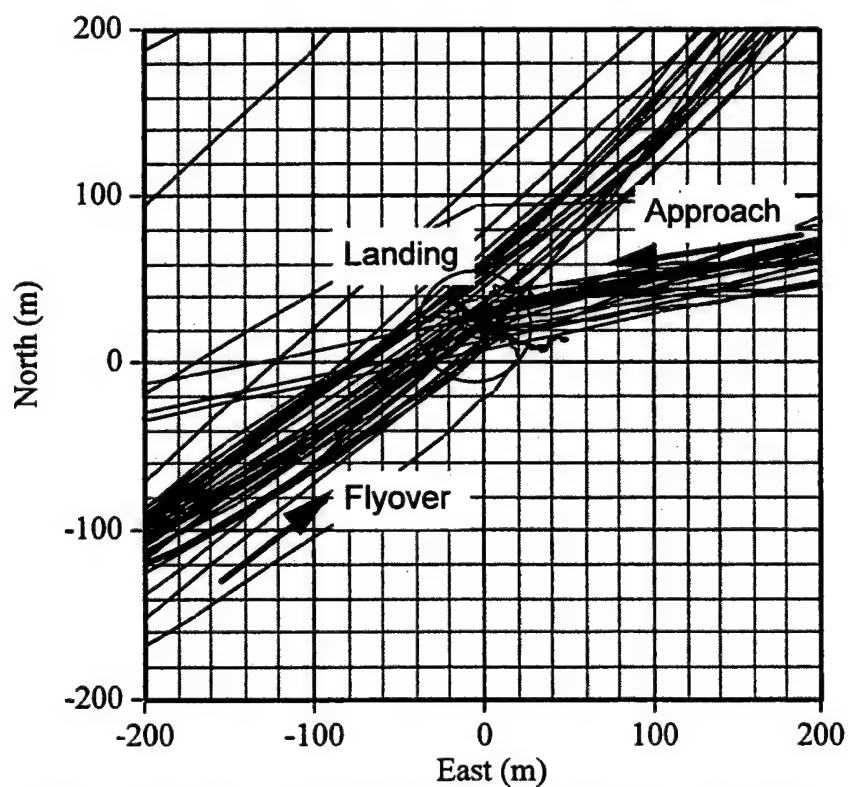
Figure 4.33 Card A Differentially Corrected Ground Tracks

4- 31
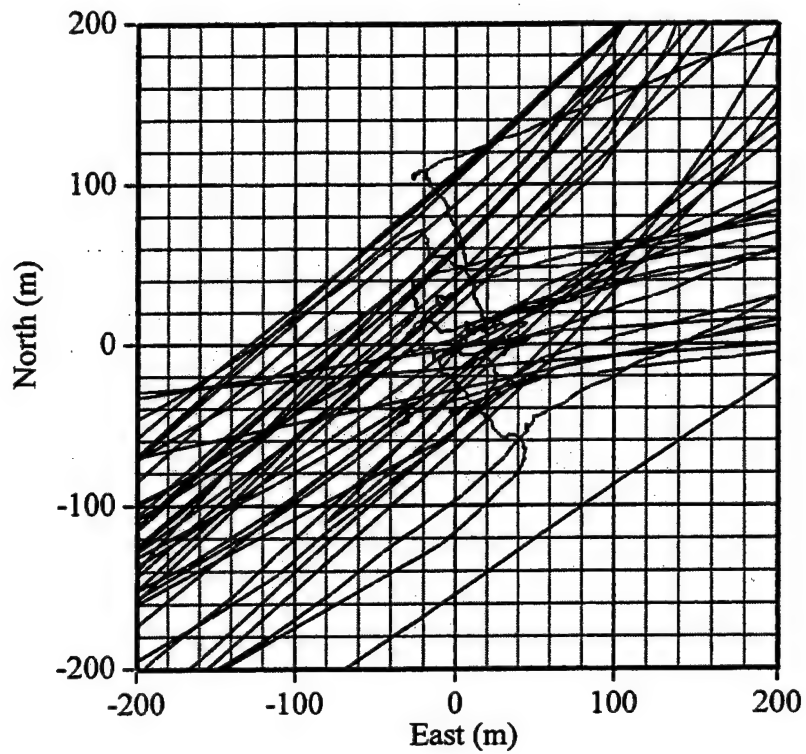
Figure 4.34 Card B Uncorrected GPS Ground Tracks
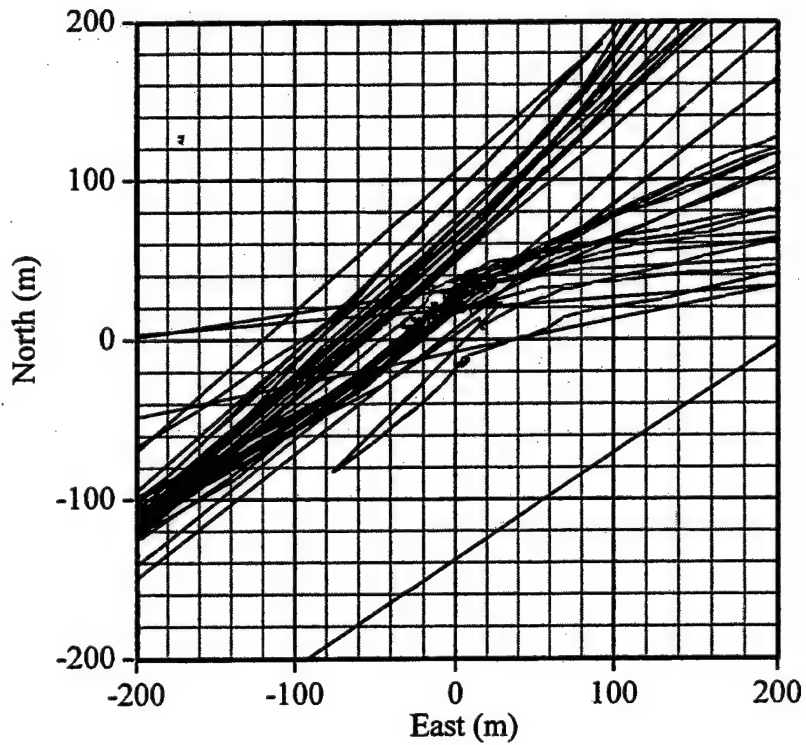
Figure 4.35 Card B Differentially Corrected Ground Tracks
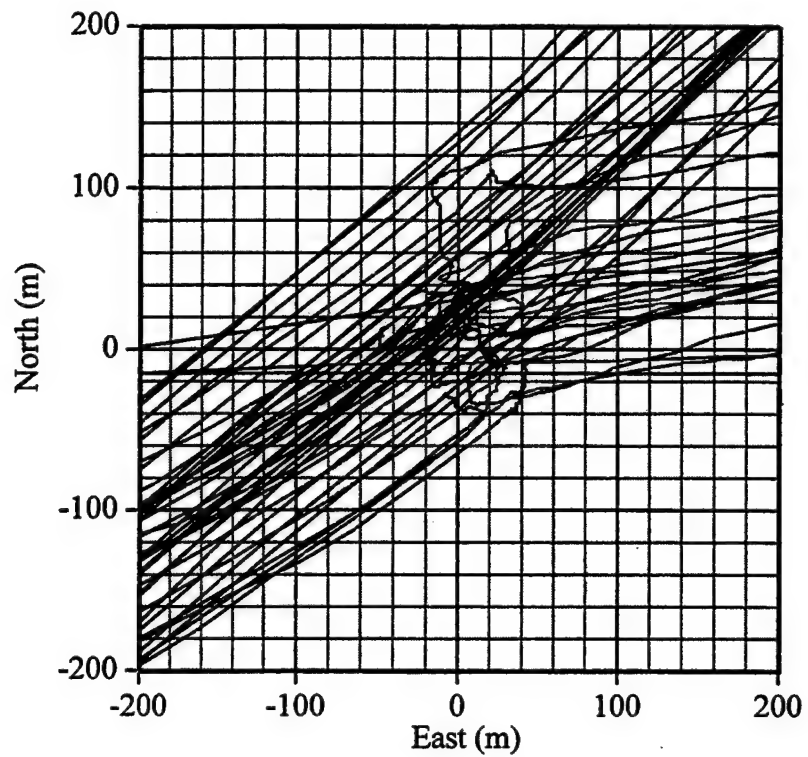
Figure 4.36 Card C Uncorrected GPS Ground Tracks
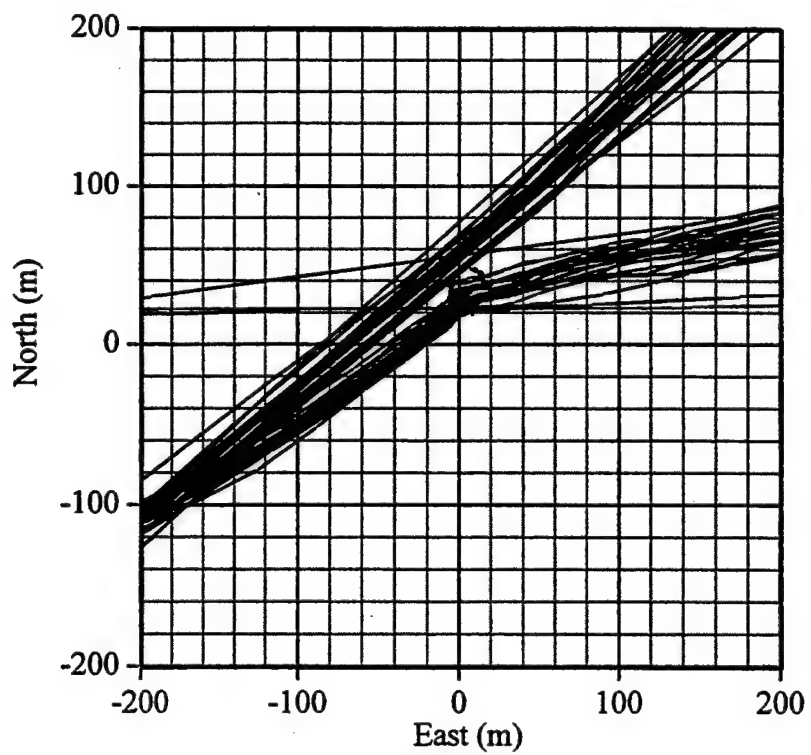
Figure 4.37 Card C Differentially Corrected Ground Tracks
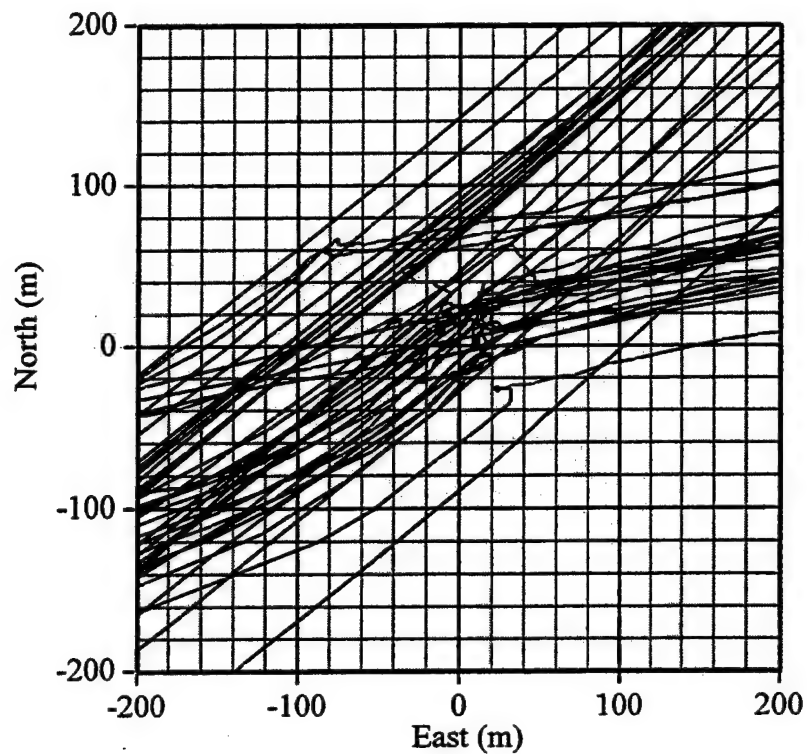
Figure 4.38 Card D Uncorrected GPS Ground Tracks
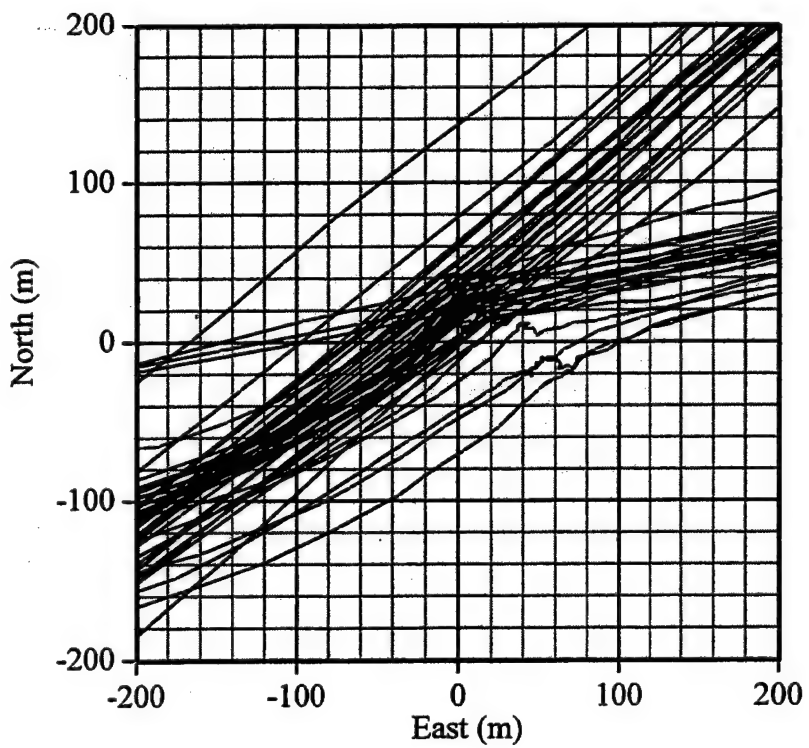
Figure 4.39 Card D Differentially Corrected Ground Tracks
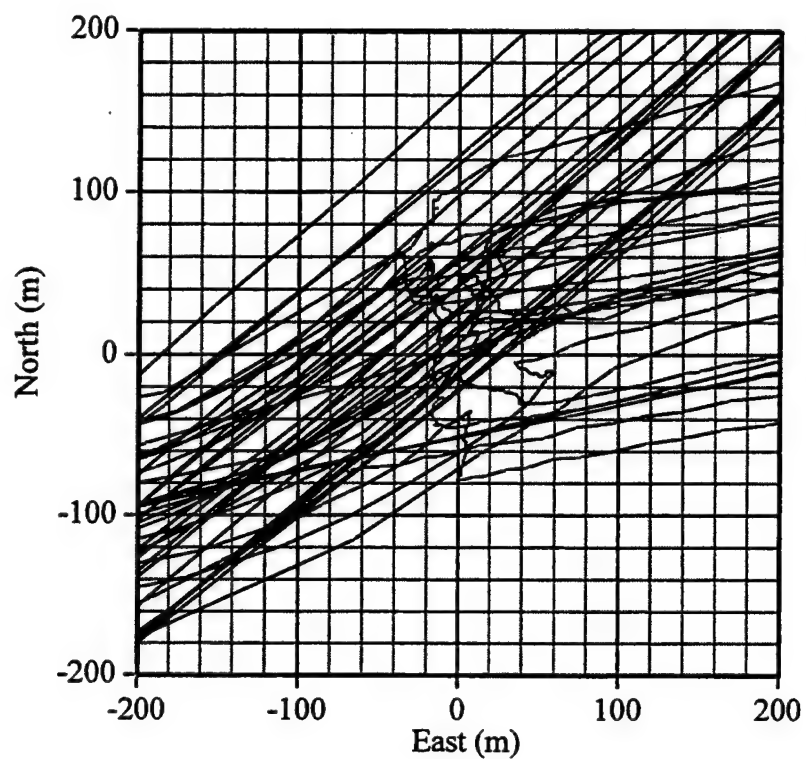
Figure 4.40 Card E Uncorrected GPS Ground Tracks
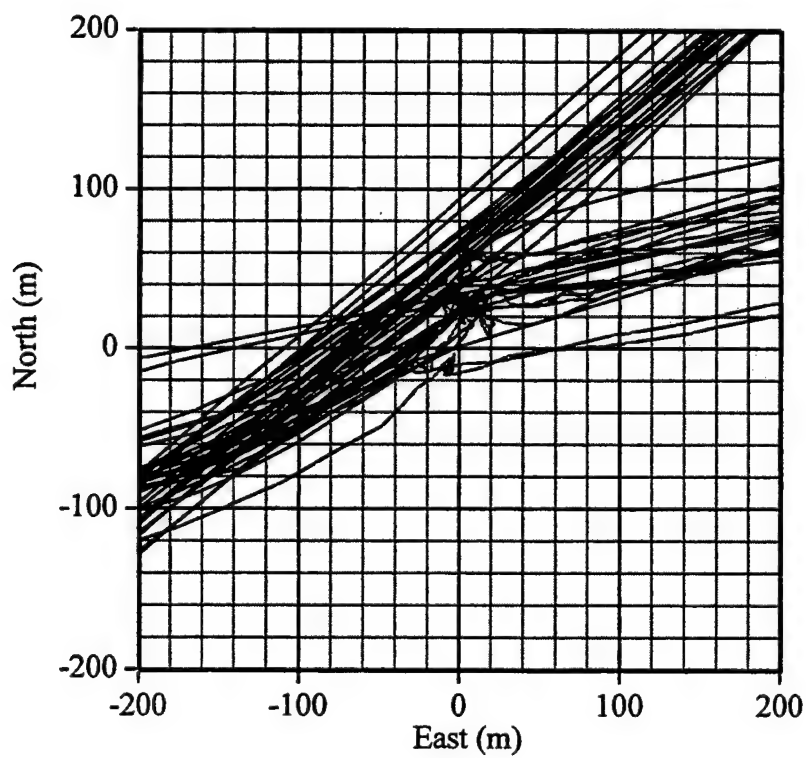
Figure 4.41 Card E Differentially Corrected Ground Tracks

4.2.4 Ground Tracks At PDK

The second acoustic test was intended to measure changes in the noise contours around PDK airport. This involved noise level measurements around the airport before, during, and after the Olympic Games. These noise level recordings were integrated averages over time and, as such, are not correlated to the track of a particular aircraft. However, the aircraft track data can be used to relate changes in the traffic patterns around the airport helipad to changes in the noise contours around the airport. Figure 4.42 shows aircraft traffic patterns into and out of PDK on a typical day during the Olympic Games.
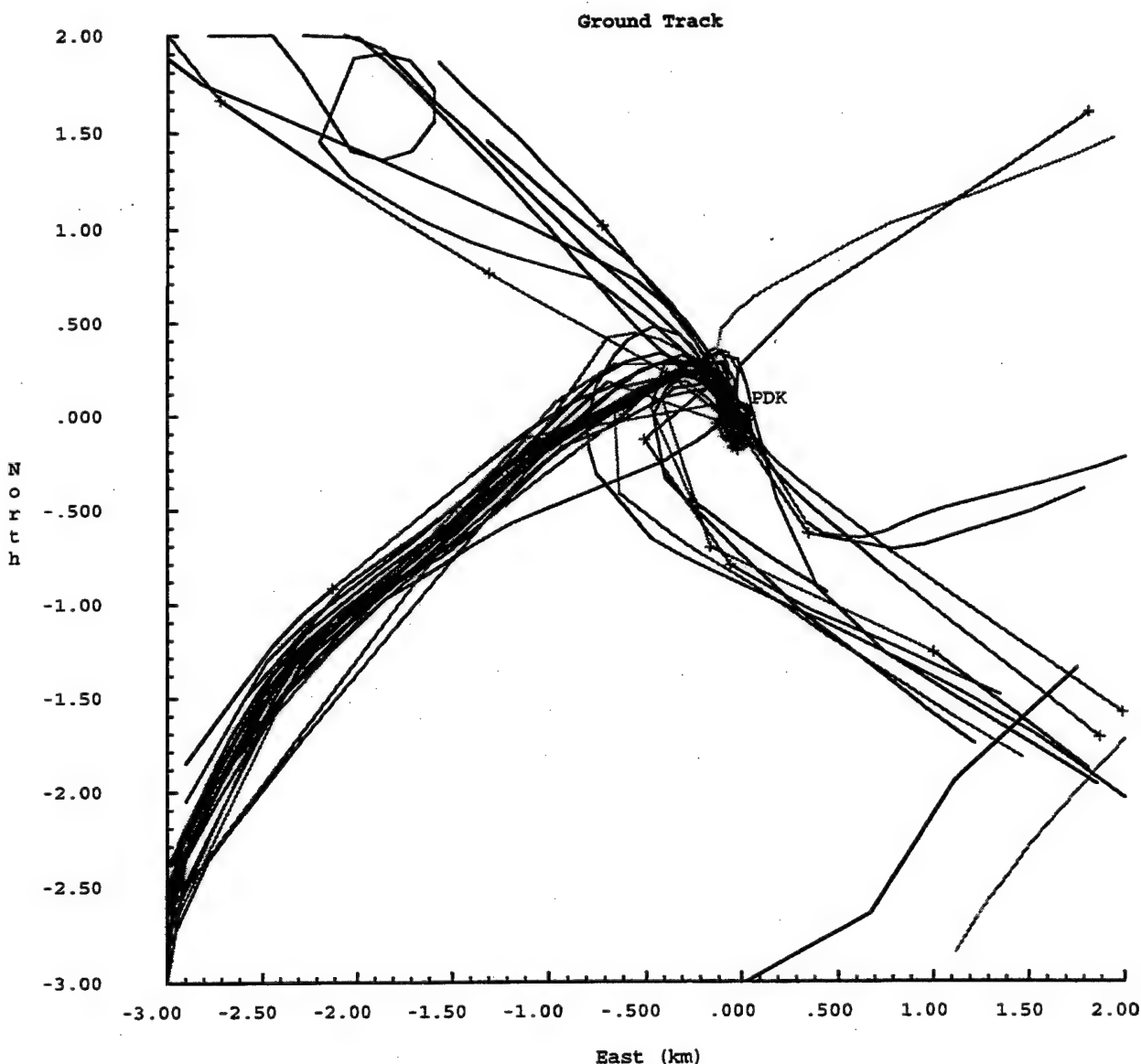
Figure 4.42 Typical Traffic Patterns Around PDK

5. CONCLUSIONS

Examination of the tracking results from the Heli-STAR demonstration has led to the following conclusions:

The ARNAV GeoNet system provides low level route coverage that has not been previously available. The transmission of GPS coordinates over a radio frequency datalink is cheaper than an equivalent radar based surveillance system.

The version of the ARNAV GeoNet system used in the Heli-STAR demonstration revealed some problems with update rates and coverage. Possible causes include aircraft installation problems, radio frequency saturation or interference, and terrain/obstacle masking.

The GeoNet system may be suitable for flight following by ATC but it is not sufficient for flight test purposes. Shortcomings include altitude accuracy and the update rate/coverage problems mentioned previously.

GPS standard positioning service accuracy (particularly altitude) is not sufficient for approach guidance. Altitude variations for the ground based unit used during the noise contour testing were ±180 m (±600 ft).

When aircraft can be "seen," the regime recognition algorithm worked well at automatically generating database information on cargo operations.

6. RECOMMENDATIONS

On the basis of what was learned during the Heli-STAR demonstration, the following recommendations are made:

A dedicated study should be undertaken to determine the cause of update rate and coverage problems experienced during the demonstration.

An effort should be made to develop an inexpensive differential altitude correction technique using the ARNAV GeoNet system.

7. REFERENCES

[1]   Parkinson, B.W. and Spilker, J.J., *Global Positioning System: Theory and Applications, Vol. I*, American Institute of Aeronautics and Astronautics, Inc., Washington DC, 1996

[2]   Parkinson, B.W. and Spilker, J.J., *Global Positioning System: Theory and Applications, Vol. II*, American Institute of Aeronautics and Astronautics, Inc., Washington DC, 1996

[3]   Clarke, B., *Aviator's Guide to GPS*, Tab Books, New York, 1996

[4]   Kaufmann, D.N., "Helicopter Approach Capability Using the Differential Global Positioning System," NASA CR 177618, August 1993.

APPENDIX A

VFR GPS NOISE ABATEMENT APPROACHES

Definitions

CEN	Central
FAWP	Final Approach Waypoint
HRP	Heliport Reference Point
IAWP	Initial approach Waypoint
MAHWP	
MAWP	Missed Approach Waypoint
MSL	Mean Sea Level
PIS	Point in Space

APPROACH: PDK

HRP (PDK 4)	Deg	Min
Latitude	33	53.045
Longitude	84	18.368

MAWP (PDK 3)	Deg	Min
Latitude	33	52.810
Longitude	84	18.889

FAWP (PDK 2)	Deg	Min
Latitude	33	52.392
Longitude	84	19.849

IAWP (PDK 1)	Deg	Min
Latitude	33	50.118
Longitude	84	21.577

MAHWP (PDK 5)	Deg	Min
Latitude	33	54.142
Longitude	84	16.451

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APPROACH: CENTRAL (CEN) POINT IN SPACE (PIS)
(For Arrivals to Hartsfield Heliport (ATL))

PIS (CEN 4)	Deg	Min
Latitude	33	39.920
Longitude	84	25.220

MAWP (CEN 3)	Deg	Min
Latitude	33	40.396
Longitude	84	25.035

FAWP (CEN 2)	Deg	Min
Latitude	33	42.302
Longitude	84	24.294

IAWP (CEN 1)	Deg	Min
Latitude	33	44.690
Longitude	84	23.420

MAHWP (CEN 5)	Deg	Min
Latitude	33	44.690
Longitude	84	23.420

APPROACH: BUC

HRP (BUC 4)	Deg	Min
Latitude	33	49.100
Longitude	84	22.100

MAWP (BUC 3)	Deg	Min
Latitude	33	49.586
Longitude	84	21.955

FAWP (BUC 2)	Deg	Min
Latitude	33	50.555
Longitude	84	21.653

IAWP (BUC 1)	Deg	Min
Latitude	33	52.392
Longitude	84	19.849

MAHWP (BUC 5)	Deg	Min
Latitude	33	48.665
Longitude	84	25.055

APPROACH: FTY

HRP (FTY 4)	Deg	Min
Latitude	33	46.324
Longitude	84	31.225

MAWP (FTY 3)	Deg	Min
Latitude	33	46.113
Longitude	84	30.682

FAWP (FTY 2)	Deg	Min
Latitude	33	45.266
Longitude	84	28.508

IAWP (FTY 1)	Deg	Min
Latitude	33	44.747
Longitude	84	26.191

MAHWP (FTY 5)	Deg	Min
Latitude	33	48.237
Longitude	84	33.228

APPROACH: GAL

HRP (GAL 4)	Deg	Min
Latitude	33	53.193
Longitude	84	27.548

MAWP (GAL 3)	Deg	Min
Latitude	33	52.839
Longitude	84	27.123

FAWP (GAL 2)	Deg	Min
Latitude	33	51.231
Longitude	84	25.867

IAWP (GAL 1)	Deg	Min
Latitude	33	49.500
Longitude	84	25.415

MAHWP (GAL 5)	Deg	Min
Latitude	33	49.500
Longitude	84	25.415

APPROACH: NOR

HRP (NOR 4)	Deg	Min
Latitude	33	55.157
Longitude	84	13.687

MAWP (NOR 3)	Deg	Min
Latitude	33	54.791
Longitude	84	14.096

FAWP (NOR 2)	Deg	Min
Latitude	33	53.500
Longitude	84	15.540

IAWPe (NOR 1E)	Deg	Min
Latitude	33	52.628
Longitude	84	15.012

IAWPw (NOR 1W)	Deg	Min
Latitude	33	52.430
Longitude	84	16.641

MAHWP (NOR 5)	Deg	Min
Latitude	33	53.500
Longitude	84	15.540

APPROACH: RAF

HRP (RAF 4)	Deg	Min
Latitude	34	3.587
Longitude	84	19.454

MAWP (RAF 3)	Deg	Min
Latitude	34	3.086
Longitude	84	19.465

FAWP (RAF 2)	Deg	Min
Latitude	34	1.290
Longitude	84	19.500

IAWP (RAF 1)	Deg	Min
Latitude	33	59.301
Longitude	84	20.295

MAHWP (RAF 5)	Deg	Min
Latitude	34	1.290
Longitude	84	19.500

APPROACH: NBS

HRP (NBS 5)	Deg	Min
Latitude	33	35.382
Longitude	84	30.893

MAWP (NBS 4)	Deg	Min
Latitude	33	35.211
Longitude	84	30.331

FAWP (NBS 3)	Deg	Min
Latitude	33	34.525
Longitude	84	28.081

IWP (NBS 2)	Deg	Min
Latitude	33	33.609
Longitude	84	24.826

IAWP (NBS 1)	Deg	Min
Latitude	33	33.609
Longitude	84	18.736

MHAWP (NBS 6)	Deg	Min
Latitude	33	33.609
Longitude	84	24.826

FEEDER 3	Deg	Min
Latitude	33	36.848
Longitude	84	17.433

FEEDER 2	Deg	Min
Latitude	33	43.263
Longitude	84	19.279

FEEDER 1	Deg	Min
Latitude	33	43.176
Longitude	84	23.748

APPENDIX B

CARGO SCHEDULES

Rt#	DEP	DES	DEP TIME	ARR TIME	Flt time	Grd Time	Helicopter
a02	pdk	mit	6:53	7:02	0:09	0:07	BO 105
a03	mit	atl	7:09	7:15	0:06	0:07	BO 105
a04	atl	nbs	7:22	7:40	0:18	0:07	BO 105
a05	nbs	fty	7:47	7:57	0:10	0:07	BO 105
a06	fty	mit	8:04	8:10	0:05	0:07	BO 105
a07	mit	gal	8:17	8:25	0:08	0:07	BO 105
a08	gal	nor	8:32	8:42	0:10	0:07	BO 105
a09	nor	nbe	8:49	8:54	0:04	0:07	BO 105
a10	nbe	pdk	9:01	9:05	0:04		BO 105
a11	pdk	buc	9:30	9:35	0:05	0:07	BELL 412
a12	buc	gbh	9:42	9:46	0:03	0:07	BELL 412
a13	gbh	mit	9:53	9:55	0:02	0:07	BELL 412
a14	mit	atl	10:02	10:08	0:06	0:07	BELL 412
a15	atl	nbs	10:15	10:34	0:18	0:07	BELL 412
a16	nbs	fty	10:41	10:51	0:10	0:07	BELL 412
a17	fty	gal	10:58	11:03	0:05	0:07	BELL 412
a18	gal	nor	11:10	11:20	0:10	0:07	BELL 412
a19	nor	pdk	11:27	11:30	0:03	0:00	BELL 412
a21	pdk	buc	12:15	12:20	0:05	0:07	BELL 412
a22	buc	gbh	12:27	12:31	0:03	0:07	BELL 412
a23	gbh	mit	12:38	12:40	0:02	0:07	BELL 412
a24	mit	atl	12:47	12:53	0:06	0:07	BELL 412
a25	atl	nbs	13:00	13:19	0:18	0:07	BELL 412
a26	nbs	fty	13:26	13:36	0:10	0:07	BELL 412
a27	fty	gal	13:43	13:48	0:05	0:07	BELL 412
a28	gal	raf	13:55	14:05	0:10	0:07	BELL 412
a29	raf	pdk	14:12	14:22	0:09	0:00	BELL 412
a31	pdk	buc	15:00	15:05	0:05	0:07	BELL 412
a32	buc	mit	15:12	15:17	0:05	0:07	BELL 412
a33	mit	atl	15:24	15:30	0:06	0:07	BELL 412
a34	atl	nbs	15:37	15:56	0:18	0:07	BELL 412
a35	nbs	fty	16:03	16:13	0:10	0:07	BELL 412
a36	fty	gbh	16:20	16:26	0:06	0:07	BELL 412
a37	gbh	gal	16:33	16:40	0:07	0:07	BELL 412
a38	gal	raf	16:47	16:57	0:10	0:07	BELL 412
a39	raf	pdk	17:04	17:13	0:09	0:00	BELL 412
a41	pdk	buc	17:45	17:50	0:05	0:07	BELL 412
a42	buc	mit	17:57	18:02	0:05	0:07	BELL 412
a43	mit	atl	18:09	18:15	0:06	0:07	BELL 412
a44	atl	nbs	18:22	18:41	0:18	0:07	BELL 412
a45	nbs	fty	18:48	18:58	0:10	0:07	BELL 412
a46	fty	gbh	19:05	19:11	0:06	0:07	BELL 412
a47	gbh	gal	19:18	19:25	0:07	0:07	BELL 412
a48	gal	nor	19:32	19:42	0:10	0:07	BELL 412
a49	nor	pdk	19:49	19:52	0:03	0:00	BELL 412

a51	pdk	buc	20:35	20:40	0:05	0:07	BELL 412
a52	buc	mit	20:47	20:52	0:05	0:07	BELL 412
a53	mit	gbh	20:59	21:01	0:02	0:07	BELL 412
a54	gbh	atl	21:08	21:15	0:06	0:07	BELL 412
a55	atl	nbs	21:22	21:40	0:18	0:07	BELL 412
a56	nbs	gbh	21:47	21:47	0:00	0:07	BELL 412
a57	gbh	fty	21:54	22:00	0:06	0:07	BELL 412
a58	fty	gbh	22:07	22:13	0:06	0:07	BELL 412
a59	gbh	atl	22:20	22:26	0:06	0:07	BELL 412
a60	atl	pdk	22:33	22:47	0:13	0:07	BELL 412

Rt#	DEP	DES	DEP TIME	ARR TIME	Flt time	Grd Time	Helicopter
b01	pdk	buc	7:12	7:17	0:05	0:07	BO 105
b02	buc	gbh	7:24	7:28	0:03	0:10	BO 105
b03	gbh	atl	7:38	7:44	0:06	0:14	BO 105
b04	atl	nbs	7:58	8:17	0:18	0:07	BO 105
b05	nbs	fty	8:24	8:34	0:10	0:10	BO 105
b06	fty	gbh	8:44	8:50	0:06	0:07	BO 105
b07	gbh	gal	8:57	9:04	0:07	0:07	BO 105
b08	gal	raf	9:11	9:21	0:10	0:07	BO 105
b09	raf	nbe	9:28	9:39	0:11	0:07	BO 105
b10	nbe	pdk	9:46	9:51	0:04		BO 105
b11	pdk	buc	9:55	10:00	0:05	0:07	BO 105
b12	buc	mit	10:07	10:12	0:05	0:07	BO 105
b13	mit	atl	10:19	10:25	0:06	0:07	BO 105
b14	atl	nbs	10:32	10:51	0:18	0:07	BO 105
b15	nbs	fty	10:58	11:08	0:10	0:07	BO 105
b16	fty	gbh	11:15	11:21	0:06	0:07	BO 105
b17	gbh	gal	11:28	11:35	0:07	0:07	BO 105
b18	gal	raf	11:42	11:52	0:10	0:07	BO 105
b19	raf	nbe	11:59	12:10	0:11	0:07	BO 105
b20	nbe	pdk	12:17	12:22	0:04		BO 105
b21	pdk	buc	12:45	12:50	0:05	0:07	BO 105
b22	buc	mit	12:57	13:02	0:05	0:04	BO 105
b23	mit	atl	13:06	13:10	0:04	0:07	BO 105
b24	atl	nbs	13:17	13:36	0:18	0:07	BO 105
b25	nbs	fty	13:43	13:53	0:10	0:07	BO 105
b26	fty	gbh	14:00	14:06	0:06	0:07	BO 105
b27	gbh	gal	14:13	14:20	0:07	0:07	BO 105
b28	gal	raf	14:27	14:37	0:10	0:07	BO 105
b29	raf	nbe	14:44	14:55	0:11	0:07	BO 105
b30	nbe	pdk	15:02	15:07	0:04		BO 105
b31	pdk	buc	15:20	15:25	0:05	0:04	BO 105
b32	buc	mit	15:29	15:34	0:05	0:07	BO 105
b33	mit	atl	15:41	15:47	0:06	0:07	BO 105
b34	atl	nbs	15:54	16:13	0:18	0:07	BO 105
b35	nbs	fty	16:20	16:30	0:10	0:07	BO 105
b36	fty	mit	16:37	16:42	0:05	0:07	BO 105
b37	mit	gal	16:49	16:57	0:08	0:07	BO 105
b38	gal	raf	17:04	17:14	0:10	0:07	BO 105
b39	raf	nor	17:21	17:29	0:08	0:05	BO 105
b89	nor	nbe	17:34	17:39	0:04	0:07	BO 105
b40	nbe	pdk	17:46	17:50	0:04		BO 105
b41	pdk	buc	18:15	18:20	0:05	0:07	BO 105
b42	buc	gbh	18:27	18:31	0:03	0:07	BO 105
b43	gbh	atl	18:38	18:44	0:06	0:07	BO 105
b44	atl	nbs	18:51	19:10	0:18	0:07	BO 105
b45	nbs	fty	19:17	19:27	0:10	0:07	BO 105
b46	fty	mit	19:34	19:39	0:05	0:07	BO 105
b47	mit	gal	19:46	19:54	0:08	0:07	BO 105
b48	gal	raf	20:01	20:11	0:10	0:07	BO 105
b49	raf	pdk	20:18	20:28	0:09		BO 105

B - 3

Rt#	DEP	DES	DEP TIME	ARR TIME	Flt time	Grd Time	Helicopter
c01	pdk	nbe	6:50	6:54	0:04	0:07	BO 105
c02	nbe	nor	7:01	7:06	0:04	0:07	BO 105
c03	nor	gal	7:13	7:23	0:10	0:09	BO 105
c04	gal	gbh	7:32	7:39	0:07	0:07	BO 105
c05	gbh	fty	7:46	7:52	0:06	0:06	BO 105
c06	fty	nbs	7:58	8:08	0:10	0:07	BO 105
c07	nbs	atl	8:15	8:33	0:18	0:07	BO 105
c08	atl	mit	8:40	8:46	0:06	0:07	BO 105
c09	mit	buc	8:53	8:58	0:05	0:07	BO 105
c10	buc	pdk	9:05	9:11	0:05		BO 105
c11	pdk	nbe	9:45	9:49	0:04	0:07	BO 105
c12	nbe	nor	9:56	10:01	0:04	0:07	BO 105
c13	nor	gal	10:08	10:18	0:10	0:07	BO 105
c14	gal	mit	10:25	10:33	0:08	0:07	BO 105
c15	mit	fty	10:40	10:45	0:05	0:07	BO 105
c16	fty	nbs	10:52	11:02	0:10	0:07	BO 105
c17	nbs	atl	11:09	11:28	0:18	0:07	BO 105
c18	atl	gbh	11:35	11:41	0:06	0:07	BO 105
c19	gbh	buc	11:48	11:52	0:03	0:07	BO 105
c20	buc	pdk	11:59	12:04	0:05		BO 105
c21	pdk	nbe	12:30	12:34	0:04	0:07	BO 105
c22	nbe	nor	12:41	12:46	0:04	0:07	BO 105
c23	nor	gal	12:53	13:03	0:10	0:07	BO 105
c24	gal	mit	13:10	13:18	0:08	0:07	BO 105
c25	mit	fty	13:25	13:30	0:05	0:07	BO 105
c26	fty	nbs	13:37	13:47	0:10	0:07	BO 105
c27	nbs	atl	13:54	14:13	0:18	0:07	BO 105
c28	atl	gbh	14:20	14:26	0:06	0:07	BO 105
c29	gbh	buc	14:33	14:37	0:03	0:07	BO 105
c30	buc	pdk	14:44	14:49	0:05		BO 105
c31	pdk	nbe	15:15	15:19	0:04	0:07	BO 105
c32	nbe	raf	15:26	15:38	0:11	0:07	BO 105
c33	raf	gal	15:45	15:55	0:10	0:07	BO 105
c34	gal	gbh	16:02	16:09	0:07	0:07	BO 105
c35	gbh	fty	16:16	16:22	0:06	0:07	BO 105
c36	fty	nbs	16:29	16:39	0:10	0:07	BO 105
c37	nbs	atl	16:46	17:04	0:18	0:07	BO 105
c38	atl	mit	17:11	17:17	0:06	0:07	BO 105
c39	mit	buc	17:24	17:29	0:05	0:07	BO 105
c40	buc	pdk	17:36	17:42	0:05		BO 105
c41	pdk	nbe	18:00	18:04	0:04	0:07	BO 105
c42	nbe	raf	18:11	18:23	0:11	0:07	BO 105
c43	raf	gal	18:30	18:40	0:10	0:07	BO 105
c44	gal	gbh	18:47	18:54	0:07	0:07	BO 105
c45	gbh	fty	19:01	19:07	0:06	0:07	BO 105
c46	fty	nbs	19:14	19:24	0:10	0:07	BO 105
c47	nbs	atl	19:31	19:49	0:18	0:07	BO 105
c48	atl	mit	19:56	20:02	0:06	0:07	BO 105
c49	mit	buc	20:09	20:14	0:05	0:07	BO 105
c50	buc	pdk	20:21	20:27	0:05		BO 105

Rt#	DEP	DES	DEP TIME	ARR TIME	Flt time	Grd Time	Helicopter
d02	pdk	nor	7:23	7:26	0:03	0:07	BO 105
d03	nor	gal	7:33	7:43	0:10	0:07	BO 105
d04	gal	mit	7:50	7:58	0:08	0:07	BO 105
d05	mit	fty	8:05	8:10	0:05	0:07	BO 105
d06	fty	nbs	8:17	8:27	0:10	0:07	BO 105
d07	nbs	atl	8:34	8:53	0:18	0:07	BO 105
d08	atl	mit	9:00	9:06	0:06	0:07	BO 105
d09	mit	buc	9:13	9:18	0:05	0:07	BO 105
d10	buc	pdk	9:25	9:30	0:05		BO 105
d11	pdk	nbe	10:00	10:04	0:04	0:07	BO 105
d12	nbe	nor	10:11	10:16	0:04	0:07	BO 105
d13	nor	gal	10:23	10:33	0:10	0:07	BO 105
d14	gal	mit	10:40	10:48	0:08	0:07	BO 105
d15	mit	fty	10:55	11:00	0:05	0:07	BO 105
d16	fty	nbs	11:07	11:17	0:10	0:07	BO 105
d17	nbs	atl	11:24	11:43	0:18	0:07	BO 105
d18	atl	gbh	11:50	11:56	0:06	0:07	BO 105
d19	gbh	buc	12:03	12:07	0:03	0:07	BO 105
d20	buc	pdk	12:14	12:19	0:05		BO 105
d21	pdk	nbe	12:45	12:49	0:04	0:07	BO 105
d22	nbe	nor	12:56	13:01	0:04	0:07	BO 105
d23	nor	gal	13:08	13:18	0:10	0:07	BO 105
d24	gal	mit	13:25	13:33	0:08	0:07	BO 105
d25	mit	fty	13:40	13:45	0:05	0:07	BO 105
d26	fty	nbs	13:52	14:02	0:10	0:07	BO 105
d27	nbs	atl	14:09	14:28	0:18	0:07	BO 105
d28	atl	gbh	14:35	14:41	0:06	0:07	BO 105
d29	gbh	buc	14:48	14:52	0:03	0:07	BO 105
d30	buc	pdk	14:59	15:04	0:05		BO 105
d31	pdk	nbe₁	15:25	15:29	0:04	0:07	BO 105
d32	nbe	raf	15:36	15:48	0:11	0:07	BO 105
d33	raf	gal	15:55	16:05	0:10	0:07	BO 105
d34	gal	mit	16:12	16:20	0:08	0:07	BO 105
d35	mit	fty	16:27	16:32	0:05	0:07	BO 105
d36	fty	nbs	16:39	16:49	0:10	0:07	BO 105
d37	nbs	atl	16:56	17:15	0:18	0:07	BO 105
d38	atl	gbh	17:22	17:28	0:06	0:08	BO 105
d39	gbh	buc	17:36	17:40	0:03	0:07	BO 105
d40	buc	pdk	17:47	17:52	0:05		BO 105
d41	pdk	nbe	18:15	18:19	0:04	0:07	BO 105
d42	nbe	raf	18:26	18:38	0:11	0:07	BO 105
d43	raf	gal	18:45	18:55	0:10	0:07	BO 105
d44	gal	mit	19:02	19:10	0:08	0:07	BO 105
d45	mit	fty	19:17	19:22	0:05	0:07	BO 105
d46	fty	nbs	19:29	19:39	0:10	0:07	BO 105
d47	nbs	atl	19:46	20:05	0:18	0:07	BO 105
d48	atl	mit	20:12	20:18	0:06	0:05	BO 105
d49	mit	pdk	20:23	20:32	0:09	0:07	BO 105

Rt#	DEP	DES	DEP TIME	ARR TIME	Flt time	Grd Time	Helicopter
e01	pdk	nor	21:45	21:48	0:03	0:12	BELL 412
e02	nor	fty	22:00	22:14	0:14	0:10	BELL 412
e03	fty	atl	22:24	22:32	0:08	0:10	BELL 412
e04	atl	pdk	22:42	22:56	0:13	0:07	BELL 412
g01	pdk	nor	5:15	5:18	0:03	0:20	BELL 412
g02	nor	atl	5:38	5:55	0:17	0:20	BELL 412
g03	atl	mit	6:15	6:21	0:06	0:06	BELL 412
g04	mit	fty	6:27	6:33	0:05	0:07	BELL 412
g05	fty	atl	6:40	6:48	0:08	0:27	BELL 412
g06	atl	fty	7:15	7:24	0:08	1:07	BELL 412
g07	fty	gbh	8:31	8:37	0:06	0:10	BELL 412
g08	gbh	pdk	8:47	8:55	0:08		BELL 412
h01	pdk	atl	5:40	5:53	0:13	0:12	BELL 412
h02	atl	nor	6:20	6:37	0:17	0:05	BELL 412
h03	nor	atl	6:49	7:06	0:17	0:11	BELL 412
h04	atl	nor	7:20	7:37	0:17	0:10	BELL 412
h05	nor	pdk	7:47	7:50	0:03		BELL 412

APPENDIX C

SPHERICAL TO LOCAL LINEAR COORDINATE FRAME TRANSFORMATION

GPS gives position reports in terms of latitude (φ), longitude (λ), and geodetic height (h) with respect to the World Geodetic System 1984 (WGS-84) map datum absolute earth coordinates. The position coordinates are expressed in degrees and the conversion of degrees to lineal distance is nonlinear. Therefore, the position report must be transformed to a local coordinate system in order to determine distance to a fixed point.

The first step of the transformation is to convert the WGS-84 coordinates of the local reference point into the Earth Centered-Earth Fixed (ECEF) reference frame. This reference frame has its origin located at the earth's center of mass, the X_E axis oriented through the equator at the Greenwich meridian, the Y_E axis 90_ to the east through the equator, and the Z_E axis oriented up through the North Pole. The relationship between the geodetic coordinates (φ,λ,h) and the ECEF coordinates (X_E, Y_E, Z_E) is as follows:

$$\begin{bmatrix} AP_{X_E} \\ AP_{Y_E} \\ AP_{Z_E} \end{bmatrix} = \begin{bmatrix} (N+h)\cos\varphi\cos\lambda \\ (N+h)\cos\varphi\sin\lambda \\ (N(1-e^2)+h\sin\varphi \end{bmatrix} \tag{1}$$

where:

$\begin{bmatrix} AP_{X_E} \\ AP_{Y_E} \\ AP_{Z_E} \end{bmatrix}$ is the position of the local reference point in the ECEF frame and

$N = \dfrac{a}{\sqrt{1-e^2\sin^2\varphi}}$, the radius of the earth ellipsoid of revolution

$e = \sqrt{\dfrac{2(a-b)}{a} - \dfrac{(a-b)^2}{a^2}}$, the eccentricity of the earth ellipsoid of revolution

a is the semi-major axis of the earth ellipsoid of revolution (6378137.0 m)
b is the semi-minor axis to the earth ellipsoid of revolution (6356752.3141 m)
φ is the geodetic latitude of the local reference point
λ is the geodetic longitude of the local reference point
h is the geodetic height of the local reference point

As a matter of convenience, the helipad at DeKalb-Peachtree Airport was chosen as the local reference point. The coordinates for PDK are listed in Table 3.1.

Once the coordinates of the local reference point in the ECEF frame are determined, the difference between the aircraft's position and the reference point can be expressed as:

$$\begin{bmatrix} \Delta_{X_E} \\ \Delta_{Y_E} \\ \Delta_{Z_E} \end{bmatrix} = \begin{bmatrix} A_{X_E} \\ A_{Y_E} \\ A_{Z_E} \end{bmatrix} - \begin{bmatrix} AP_{X_E} \\ AP_{Y_E} \\ AP_{Z_E} \end{bmatrix} \tag{2}$$

where,

$\begin{bmatrix} A_{X_E} \\ A_{Y_E} \\ A_{Z_E} \end{bmatrix}$ is the position of another GeoLink unit in the ECEF reference frame.

After the aircraft's relative position is found in the ECEF frame, it is transformed in the local coordinate system. This system has the PDK helipad as the origin with the X_H axis oriented True North, Y_H oriented due East, and Z_H oriented down, normal to the helipad. The transformation is:

$$\begin{bmatrix} A_{X_H} \\ A_{Y_H} \\ A_{Z_H} \end{bmatrix} = \begin{bmatrix} C_E^H \end{bmatrix} \begin{bmatrix} \Delta_{X_E} \\ \Delta_{Y_E} \\ \Delta_{Z_E} \end{bmatrix} \tag{3}$$

where,

$\begin{bmatrix} A_{X_H} \\ A_{Y_H} \\ A_{Z_H} \end{bmatrix}$ is the aircraft's position relative to the reference point in the local frame coordinates, and

$C_E^H = \begin{bmatrix} -\sin\varphi\cos\lambda & -\sin\varphi\sin\lambda & \cos\varphi \\ -\sin\lambda & \cos\lambda & 0 \\ -\cos\varphi\cos\lambda & -\cos\varphi\sin\lambda & -\sin\varphi \end{bmatrix}$, the transformation matrix from the ECEF frame

to the local reference frame.